THE USE

OF THE

STEAM-ENGINE INDICATOR.

BY

LYMAN.

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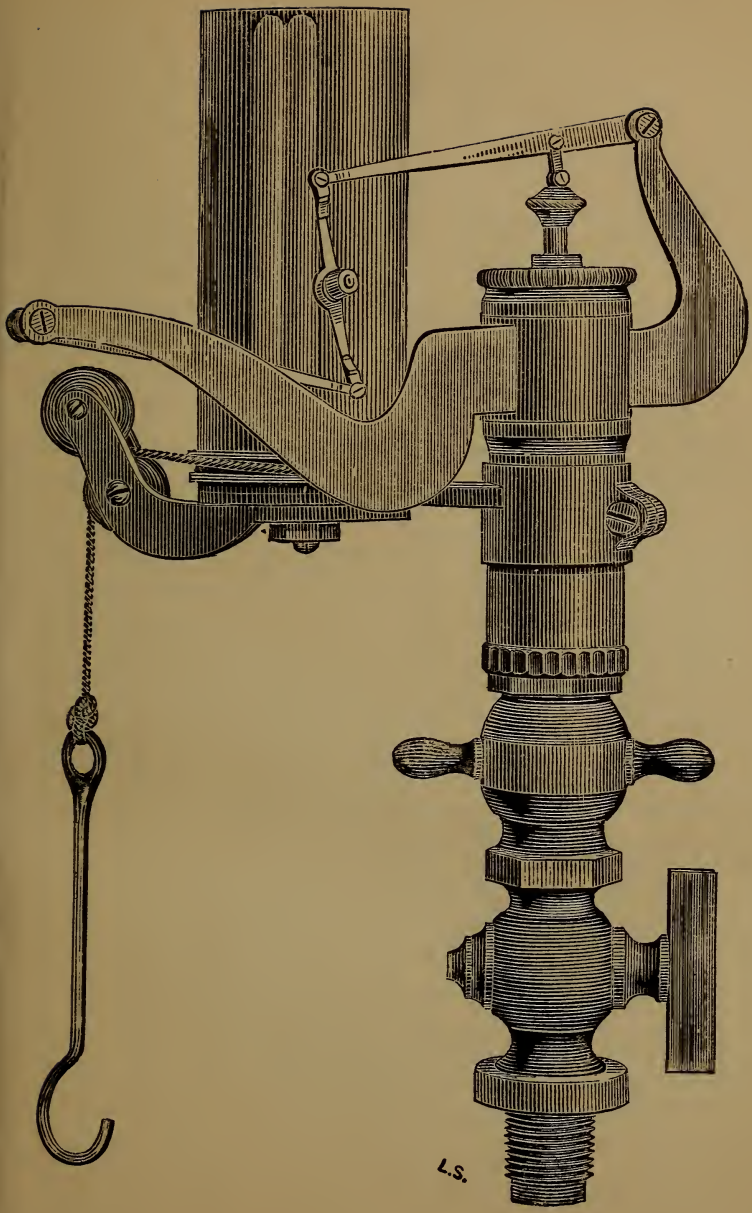
L.S.

THE USE

OF THE

STEAM-ENGINE INDICATOR:

OR,

Practical Science for Practical Men.

BY EDWARD LYMAN, C. E.,

MEMBER OF THE AMERICAN INSTITUTE OF MINING ENGINEERS; PUBLISHER OF THE AMERICAN STANDARD OF BOLTS AND NUTS (CHART); LYMAN'S GEAR CHART, AND UNIVERSAL SCREW CUTTING INDEX, ETC., ETC.

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TO THE

OWNERS AND USERS

OF

STEAM POWER,

WHO ARE ENDEAVORING, BY THE USE OF THE BEST KNOW APPLIANCES FOR THAT PURPOSE, TO ECONOMISE IN THE

CONSUMPTION OF FUEL,

THIS VOLUME IS RESPECTFLLLY DEDICATED,

BY THE AUTHOR.

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PREFACE.

In the following pages the author proposes to set forth some things which have been *done* by the "use of the Steam-engine Indicator," and hopes thereby to make the body of the work conform to the title-page. Most writers upon this subject make use of rules, formulas, and mathematical matter, which, to the professional man may be acceptable enough, but to the busy manufacturer and the practical engineer these formulas are dry reading. Said a large manufacturer to me once in the City of New York, "I care very little for the scientific principles upon which these things are based; *results* are what I want." And so it is with the busy men of these times: satisfy them of the *results*, and that is what they will pay liberally for; they are willing to leave the discussion of the scientific part to experts. Satisfy any sane man that he is burning two pounds of coal where one pound would do his work, and advise him of the best means under the circumstances of bringing about the reduc-

tion, and so far your duty is done and you are justly entitled to the measure of praise of him "who makes *two* blades of grass grow where *one* grew before."

This work plainly shows the difference between good and bad diagrams, as they are selected from the regular practice of the author, with reference to the special business in hand, and any person who is operating with steam as a motive power, may peruse these pages with pleasure and profit. To the student of steam and mechanical engineering, this volume will aid him in his researches in a marked degree, and will hold its interest to the end, being as it is a practical work of to-day; and, to the general reader, an hour spent with this book will well repay you by its addition to your stock of general information, of what it has to say of the principles of the leading great PRIME MOVER of the Nineteenth Century.

E. LYMAN, C. E.

NEW HAVEN, October, 1874.

THE USE

OF THE

STEAM-ENGINE INDICATOR.

THE STEAM-ENGINE INDICATOR is a small instrument (*see Frontispiece*) which may be attached at any time to the cylinder of a steam-engine, at either end or both, by a pipe usually about half an inch in diameter. Then, by attaching the cord of the Indicator to some part of the engine having motion coincident with the piston, and placing a piece of paper upon the cylinder of the Indicator, admitting steam through the pipe, and then applying the pencil of the Indicator to the paper, a card or diagram is traced. This is done when the engine is regularly working, either loaded heavily or light, making no delay to the manufacturing business to which the engine is attached. By this card, which is called the "Indicator card" or diagram, the working condition of the engine is positively shown as it can be in no

other way. In fact, as has been said, "it is the stethescope of the physician, revealing the nature of the disease in the vitals of the patient."

By this card is shown the horse-power of the engine under any given load, so that if there are two or more parties using power from the same engine, by taking a card with each one's work attached, it can be shown just how much each party is using. It shows the condition of the valves, whether they are set right or not—serious losses of power occur from this cause; whether the piston or valves leak, or whether the passages are large enough or not; the amount of steam consumed by the engine in a given time, from which may be estimated the amount of water evaporated, and the amount of coal consumed to evaporate that water. A first-class engine, if working properly as it should, ought to furnish one horse-power with a consumption of from 2½ to 3 pounds of good coal per hour; but many engines at the present day are using more than double that amount, showing a flagrant waste.

The writer proposes to show in this work a series of diagrams of good and bad forms, that have been taken in his own practice, and in connection with them to point out the course pursued by him to correct the bad ones and give the results that have been attained, in order that the readers may form their own opinions

and be the better able to judge of what course to pursue if they are in any way desirous of reducing their expenditure for fuel—at all times dear enough, and in the present depressed state of manufacturing interests, a matter for very serious consideration.

In what may be said in these pages the writer will endeavor by all means to avoid personalities of every kind, hence the names of the makers of engines referred to will be omitted, the purpose being to deal exclusively with principles and not engender strife among the different builders in a work of this public character. If the writer himself is consulted on the matters of which this book treats, he will give his opinion, after examining the engine, of the best course to be pursued under the circumstances, reference being had to all the points in the case. Sometimes it becomes the engineer's duty to recommend a new engine; sometimes a new cylinder, and possibly some modification of the valve-gearing or valves. In some cases, by very slight ajustments which may be done in half an hour's time by an intelligent mechanic, the engine may be put in proper condition and a saving of from 5 to 15 or 20 per cent. effected. In many cases engines are set up in a bad way, having too much or too little speed, and, by making changes in the speed, the power may be very materially effected with economical results. It is im-

possible to state all cases. Almost every application of the Indicator pesents different conditions—some of them novel—for the consideration of the engineer and proprietor. The writer has a very large number of diagrams that he has taken himself from different engines, besides others that have come into his possession in various ways: some viciously bad, others as good as could be expected or as need be desired, showing very economical results. The several lines of the diagram are designated in the following manner:

The Atmospheric Line.
The Perfect Vacuum Line.
The Admission Line.
The Steam Line.
The Expansion Line.
The Exhaust Line.
The Counter-pressure Line.
The Compression Line.

In non-condensing or high-pressure engines there is no vacuum, consequently the diagram is as it should be, all above the atmospheric line. In low-pressure engines the counter-pressure line should come down to 13 or 14 pounds below the atmospheric line. I have cards that I have taken that do this, and where the Indicator shows the same vacuum in the cylinder that

the vacuum gauge shows in the condenser, a result which, where the vacuum is reasonably low, is all that could be desired.

Diagram No. 1 is a theoretically perfect diagram, showing the expansion curve correct, with the steam cut-off at one-fifth the stroke. An approximation to this perfect diagram is all that can ever be attained in practice with an Indicator; but the nearer to it the diagrams come the better is the engine from which they are taken. Two points may be especially noticed:

1st. That engine will give the greatest horse-power, with the least consumption of fuel, which unites the highest initial pressure with the lowest terminal pressure.

2d. The vice to be especially deprecated is that technically known among engineers as *wire drawing*, in which the steam line runs along with possibly an undulatory movement; starting low, perhaps 30 pounds or more below the pressure in the boiler, and terminating very nearly as high as it started. An engine showing such a diagram will yield a small amount of power, but it will consume a large amount of fuel ; and here may possibly be the source of an explosion. The boiler pressure is not even approximately reached in the cylinder, by possibly 30 or 40 pounds; the engine

does not do its work satisfactorily; the safety-valve weight is moved out on the lever, and the boiler is over-crowded and has to suffer, when the real cause of all the difficulty is with the engine and its attachments.

Engines for different purposes will, in the good judgment of the engineer, require to show somewhat different diagrams. For instance, driving a stationary engine for running a train of rolls in an iron or steel rail mill will be quite a different business from driving a propeller on board of a steam vessel; the former will have a very fluctuating load, say from 100 to 600 horse-power, requiring the constant action of a complete governing apparatus, while the latter will work right up to the actual power of the engine and keep right along at a uniform rate of power, subject to occasional adjustments at the hands of the engineer on the watch. For ship purposes the writer believes there is great merit in the double cylinder or compound engine, that is, working the steam at high pressure in one cylinder and from that into another at low pressure, either with or without an intervening reservoir; and this may be brought into more general use for stationary purposes, but as yet it has not been very much used. The writer knows of one instance where a party offered a neighbor of his

ten dollars a year for his exhaust steam, from a high-pressure engine, for a term of years. This he turns into a cylinder which he works below the pressure of the atmosphere, and it furnishes him ample power to drive a machine shop of some magnitude, I should say not less than five nor more than ten horse-power. It is, by all means, the most economical steam-power within the present knowledge of the writer.

There are many claimants for favor among the various styles of engines, and most of them have some points of excellence; but there are so many conflicting statements in reference to them that parties wishing to purchase, not having personal knowledge of them, may well be in doubt as to the most economical kind to procure; but, in such cases, let every judicious man ask to see the Indicator diagrams and when produced, if he is not familiar with them himself, let him refer them to some one who is. Let each engine stand on its own merits, for the Indicator is a sure and unfailing witness, and in the hands of a careful and experienced man will tell no wrong stories. To the present owners of engines I would say that the periodical application of the Indicator to your engines will be found to result in a uniform reduction of your fuel bills, and be a very general source of satisfaction to all having direct connection in any way with your steam-power.

Diagram No. 2 was taken from an engine of 22 in. bore by 15 in. stroke, by the writer. It was a plain slide-valve engine, of the ordinary kind. I recommended an independent adjustable cut-off, which was put on at an expense of about $300. This engine, when this diagram was taken, required an evaporation of about 200 gallons of water per hour.

Diagram No. 3 was taken from the same engine after the above change was made, and doing the same work. It now required an evaporation of 150 gallons of water per hour—a plain case of saving 25 per cent.

Diagram No. 4 was taken from an engine similar to the one No. 2 was taken from, and under similar circumstances. The same change was recommended and the same results reached, as shown by diagram No. 5, which was taken after the change, to wit, about 25 per cent. The 25 per cent. saving in coal, in each of the above cases, amounted to about 50 pounds per hour, or 500 pounds per day of ten hours, which, at $8 per ton, amounts to $2 per day, or say $600 a year.

Diagram No. 6 was taken from a steam yacht that the owner supposed was in perfect working order until the application of the Indicator. It is a very bad diagram and shows late admission, the engine not getting its steam until the piston had passed the middle

of its stroke. This diagram was from the lower end of the cylinder, and the valve was balanced; there was lost motion in the connections, and the weight of the valve kept it down, thus it did not open the port until it was a fourth of a revolution at least too late. Remedy—Take out the lost motion and re-set the valve. Result—A gain in power, with the same steam, of about 20 per cent.

Diagrams No. 7 are a pair, taken from both ends of one of a pair of low-pressure engines. They show characteristics peculiar to the class of engines to which they belong. Both engines show similar diagrams, and they are bad. They show back-pressure of about 35 per cent. At the time these diagrams were taken the vacuum gauge showed 25 inches in the condenser, which is equal to about 12½ pounds, while in the cylinder only 5 pounds vacuum on the crank-end and 6 pounds on the out end, is obtained. The trouble with these engines, in this particular, is, that the exhaust passages from the cylinder to the condenser are insufficient; they are too small and too long, and very crooked. The steam passages also are too small. When these cards were taken the steam pressure, per gauge in the boilers, was 75 pounds. One of the cards only reaches 54 pounds, and the other only 50 pounds. Correcting the foregoing evils on these engines, which

can probably be done at an expense of about $10,000, will produce a saving of upwards of 50 per cent., which will amount to about 1,200 pounds of coal per hour. The engines are used about twenty hours per day, which would effect the saving, in round numbers, of about 12 tons per day, equal, at $8 per ton, to $96, or about $29,000 annually; a waste which, when contemplated in the light of these times, is something enormous.

Diagram No. 8 was taken by the writer from a small engine of 6 in. bore by 12 in. stroke, and is somewhat peculiar. The engine was running at a high rate of speed — 225 revolutions per minute — and doing very little work; yet it shows a high initial and a low terminal pressure, fulfilling the conditions of a first-class engine. The high speed at which it was taken caused the movement of the Indicator piston to be somewhat vibratory, so much so that the vibrations of the expansion line cause it to cross the compression line. All of the movements are in correct time, and it is a good diagram. It was taken at the suggestion of the builder, in the presence of the owner, in order to ascertain if it was working all right, and the result proved highly satisfactory.

Diagram No. 9 was taken from an engine that was noticed to be using more steam than formerly. It was

an engine with an independent cut-off, and the trouble with it was that when cutting off short the construction was such that the cut-off passed by the opening in the main valve and opened the port for steam a second time. The card on this engine, as it was running, required the use of 315 pounds of coal per hour. The writer had the cut-off adjusted to follow a little farther, when

Diagram No. 10 was taken, which is very good; the same engine, with this card, only requiring 150 pounds of coal per hour. A plain case of saving upwards of 50 per cent.; whereas it was using about 1½ tons of coal in ten hours, it now uses about three-fourths of a ton.

Diagram No. 11 was taken by the writer from an engine of 54 in. bore and 36 in. stroke, low-pressure, direct-acting, upright. It shows trouble with both the steam and exhaust passages. When this card was taken the vacuum gauge showed 25 inches of vacuum, equal to about 12½ pounds, but only 8 pounds was obtained in the cylinder, and that just at the end of the return stroke. The pressure of steam in the boiler at the same time was 60 pounds, but the pressure in the cylinder only reached 25 pounds—a failure to come up of 35 pounds. The writer with others, in consultation with the owners, recommended a new cylinder of 44 in.

diameter, and a differently constructed valve-gear. The change was made under the supervision of the writer at an expense to the proprietors of about $5,000. By this diagram the coal required was about 1,700 pounds per hour.

Diagram No. 12 was taken from the new cylinder when it was doing precisely the same work as the old one, when No. 11 was taken, and it only required a consumption of 770 pounds of coal per hour, making a saving of about 55 per cent. The actual facts, as taken from the coal account for a two-weeks run with each cylinder, show a saving, when reduced to dollars and cents, in favor of the new cylinder, of $60 every 24 hours; the engine is worked double turn, and being worked to its maximum duty for say 200 days in each year, gives a saving to the proprietors of $12,000 annually. The new cylinder disposed of the use of three boilers, each 15 ft. long by 5 ft. diameter, with a dome 4 ft. high by 3 ft. diameter, each boiler having forty-two 4-in. tubes, and made lighter firing on the remaining boilers.

Diagram No. 13 was taken from an engine of a first-class make, high-pressure. It had been running some time, been excessively loaded, and had become worn. The effect of the wear, here shown, is, that the movements are behind time. There is no steam-

lead, and, besides, the piston advanced fully one-tenth of the stroke before the maximum pressure was reached in the cylinder. If the exhaust had opened a little sooner, the counter-pressure line would have run lower; all of which would have enlarged the area enclosed by the diagram, and so have shown a development of more power than is now shown. The remedy is easy of application, which is, to renew the lifters, and make them of the proper length to lift the valves in time. The writer examined this engine with the Indicator, together with others at the same time, for the same company, and directed repairs to be made on them similar to the above, about six months ago. He has received notice to come and examine them all again, together with others which have since been started by the company.

Another application of the Indicator, of very great importance, is to test the steam-gauge. This is done when the Indicator is attached, by putting the engine on the center, admitting steam to the Indicator, and seeing whether the Indicator and steam-gauge agree or not. Most steam-gauges, of any spring construction, vary from the correct pressure.

Diagram No. 14 was taken for the above purpose, and was found to agree perfectly — a result seldom found, a common deviation being from 1 to 5 pounds,

sometimes 8 pounds, and in one instance as high as 15 pounds out of the way. Quite enough, in some cases, to account for disaster to the boiler.

Diagram No. 15 shows the result of attaching a condenser to a first-class cut-off engine, of high-pressure, and working it low-pressure. This card shows 62 per cent. below the atmospheric line, on a development of twenty-nine horse-power, which shows a credit to the condenser of seventeen horse-power—less the amount taken to work the air-pump, which probably does not exceed one horse-power.

Diagram No. 16 was taken quite recently by the writer, and shows a pretty bad state of affairs. After a complete summing up it shows the astonishing fact that the engine from which it was taken is using 12 pounds of good coal per horse-power per hour; a waste of fully 75 per cent., and this 75 per cent., in this case, amounts to $7.80 per day.

With reference to horse-power, the rule used in this work is that which was used by Watt, viz., 33,000 pounds raised one foot high in a minute; and just here a few words upon horse-power will not be out of place.

A boiler of good evaporative efficiency will evaporate, under favorable circumstances, from 8 to 12 pounds of water with one pound of good coal. Now, how much horse-power is this? Let us see. Take for

example Diagram No. 15. Here we have a development of twenty-nine horse-power and a required evaporation of 780 pounds of water per hour, giving to each horse-power 27 pounds of water per hour. Now, if this boiler is competent to evaporate 10 pounds of water with 1 pound of coal, which doubtless it is, it will give $2\frac{7}{10}$ pounds of coal per horse-power per hour.

Again, take Diagram No. 16, where it was found that the engine used 12 pounds of coal per horse-power per hour, and assuming that the boilers evaporate 10 pounds of water with 1 pound of coal, as the writer believes they do, then there is used 120 pounds of water per horse-power her hour. As was said in reference to Diagram No. 16, that there was a waste of 75 per cent., it will now be seen that 27 pounds of water in the former case is $22\frac{1}{2}$ per cent. of 120 pounds in the latter, the whole difficulty being entirely with the engine.

A cubic foot of water weighs about $62\frac{1}{2}$ pounds, and assuming that evaporated as equal to one horse-power (see Reports of Committees on boiler horse-power, *Journal of the Franklin Institute*, December 1873, page 397), then the 120 pounds in the latter case is equal to 192 per cent., while the 27 pounds in the former case amounts to 43 per cent., again making the former $22\frac{1}{2}$ per cent. of the latter.

The foregoing is sufficient, in this place, to show what the writer desires : that so far as the consumption of fuel is concerned, a horse-power in one engine is a very different thing from what it is in another, and to direct the attention of steam users particularly to this difference, that the power in both cases is precisely the same, only that one engine wastes steam to the amount of 75 per cent. while the other utilizes it fully. At this point I trust my readers will see and appreciate the USE OF THE STEAM-ENGINE INDICATOR, which opens to the view of owners of steam-power such facts as have here been stated.

Said an engineer of much ability to me recently, "You may run a 100 horse-power boiler up to its full capacity, and I will work all of that steam through a ten horse-power engine," thereby meaning that it was a comparatively easy matter to waste 90 per cent. of the steam. In the case of Diagram No. 16, cited above, there are two 100 horse-power boilers, being run nearly to their full capacity, and only doing thirty horse-power work. The committee of the Franklin Institute, previously referred to, having had the subject of boiler horse-power under consideration for about three years, were discharged, having seen no good reason for changing the English standard—that of one cubic foot of water evaporated into steam, at atmospheric pressure,

as one boiler horse-power; that is to say, a boiler having heating surface enough, combined with grate surface enough, to evaporate ten cubic feet of water in one hour is equal to a ten horse-power boiler, or is a commercial ten horse-power boiler.

Now, what amount of heating and grate surface is necessary to evaporate a cubic foot of water per hour? On this point makers disagree. Most men will consider the foregoing a very large allowance for one horse-power; but, going back again to the English practice—and they have allowed in some instances one square yard of effective heating surface, and one square foot of fire grate for one horse-power, that is, to evaporate one cubic foot of water per hour—and assuming this to be correct, then you may vary either of them at pleasure, within certain limits. For instance, you can enlarge your heating surface and reduce the size of the fire grate.

RULE FOR FINDING THE HORSE-POWER OF STEAM BOILERS BY USE OF THE ENGINEERS SLIDE RULE.

Rule.—Reverse the slide and set the area of effective heating surface, in square yards, on C, to the area of fire grate, in square feet, on A, and looking to the left or right, as the case may be, the first two divisions

of the same value that coincide with each other are the horse-power of the boiler, when thus arranged.

Example.—Suppose you have 16 square yards of effective heating surface in a boiler, with a fire grate of 25 square feet, and you wish to know the most suitable rate to work the boiler at ; then on the slide rule, with the slide inverted, set 16 on C, against 25 on A, and, looking to the left, the first two divisions of the same value on A and C, that coincide with each other, are those of 20, and they represent the horse-power of the boiler, viz., twenty horse-power; or, in other words, according to the English standard, a boiler having 16 square yards of effective heating surface, and 25 square feet of fire grate, will evaporate 20 cubic feet of water per hour. Again, suppose that a boiler is intended to drive a thirty horse-power engine, but it has only 25 square yards of surface and the area of the fire grate is required, then, using the slide rule, invert the slide (which is, simply changing ends with it), and set 30 on C against 30 on A, and, looking to the right hand, you will find against 25 yards of surface on C, the answer to be nearly 36 square feet of fire grate upon A; and, in like manner, against any number expressing the square yards of effective heating surface on C, you will find the number of square feet of fire grate most suitable for the given power upon A. In short, the inverted line C

represents a table of thirty horse-power boilers, with various areas of surface, and the line A represents a table of areas of fire grates corresponding to those surfaces :

A	30	Fire grate.....	31	34	36	39	45
○	30	Heating surface .	29	26½	25	23	20

The inverted slide rule, when thus set, exhibits at a glance the various ways in which a thirty horse-power boiler may be set up. It will be seen that any one of these three principal data respecting boilers may thus be found when the other two are given by any workman in the possession of a slide rule.*

Now, if any of my readers demur from the data here given, as to the quantity of heating surface or grate surface necessary to evaporate one cubic foot of water per hour, all that is necessary for them to do is to change the amounts of either, or both, and the calculations will then be just as easily made on the slide rule as with the given amounts. Suppose, for example, that you assume half a square yard of heating surface and half a square foot of fire grate, then one half of the above results would be the correct data, or whatever fraction of the data above given you assume, the

* See advertisement of slide rules and books at the end of this volume.

amounts are readily computed on the slide rule by direct proportion.

HOW TO TAKE A DIAGRAM.

CONNECTING THE INDICATOR TO THE CYLINDER.

If the cylinder has not been drilled for the Indicator, have it drilled. If it is a horizontal engine, on the top side of the cylinder, at both ends, as near the ends as possible, so as to be sure that the piston does not cover the hole, and tap the holes out with a half-inch pipe tap and then we can screw the Indicator fittings right into the cylinder, or put in a nipple and attach the Indicator to that, and when we are done the holes can be plugged up by screwing in a half-inch gas-pipe plug. Then the engine can always be indicated at any time; or the holes may be drilled in the cylinder heads, and angular connections used; or, diagrams may be taken from the cocks in the cylinder where the water is drawn off, but the diagram is not as sure to be reliable. In any case the opening should never be less than half an inch in diameter, and be as short and direct as possible, avoiding all unnecessary bends; the object being to have the pressure in the Indicator exactly the same as it is in the cylinder of the engine, for upon this pressure all our calculations are based. It is desirable that

the Indicator stand upright, as shown in the engraving, although cards can be taken with it standing at an angle. It is also necessary that it be set up firm, for, if it stands loosely, the cord may pull it from its original position, and thus destroy the accuracy of the diagram.

If the engine is vertical, it may be drilled in one side of the cylinder, close to the top and bottom; at the bottom end it will *have* to be drilled in the side, while the top may be drilled in the cylinder cover, or the tallow-cup may be removed and the Indicator inserted in its place. Good judgment will soon decide where the best place to connect with the cylinder is.

MOTION OF THE PAPER CYLINDER—CONNECTING THE CORD.

Having preparations made as described for attaching the Indicator to the cylinder, the next thing is to provide a motion to partially rotate the paper cylinder of the Indicator, which is perfectly coincident with the motion of the piston, and for this purpose the motion of the piston must be reduced to about 4 inches, more or less. The Indicator will take a card nearly 6 inches long, and it is desirable it should be as long as possible; but if the motion is too long it is quite liable to cause trouble, by making the paper cylinder strike the stops, which must be avoided or the diagram

will be a failure. If the motion of the engine is slow enough to admit of it, a diagram 4 to 4½ in. long, will be a very good length, but if the motion of the engine is fast it will have to be taken shorter. (See diagram No. 8, which was taken at a speed of 225 revolutions per minute.)

If the engine is a beam-engine, or has vibrating arms connected in any manner with the cross-head, as some condensing engines have for working the air-pumps, then, by going towards the beam center, or towards the centre on which the arms vibrate, near enough to get a movement of 4 or 4½ in., more or less, there you may attach your cord; then set the engine piston in the middle of its travel and lead off your cord and fix a carrying pully in such a position that the cord will be at right angles to whatever gives it motion. After this you may carry it to the Indicator in any direction you please. Then fix a running-loop, so you can readily shorten or lengthen your cord, and you can hook it to the cord on the paper cylinder when ready; but in a large majority of cases no such ready means of getting the motion as has been described will be found, and the engineer will sometimes have to tax his ingenuity sufficiently to get up a means of reducing the motion in a horizontal engine, of say 4 ft. stroke, to 4 in. The writer has had occasion to do two such cases

within the week this was written, and it was done in this way: Cut a narrow strip of board, say 1 in. thick and 4 in. wide at one end, and 3 in. wide at the other, and 10 or 12 feet long, according as there is room. Make a hole in both ends, and make the wide end fast, by a bolt through the hole, to anything that is handy; or something temporary may be set up for the purpose, so that the board will lay horizontal. Then erect a board frame under the point of the board near the bed of the engine, for the board to slide back and forth on and not fall down, and connect the board to the cross-head by means of a connection made of a piece of iron, say 1 in. by ¼ in., which may be connected by one of the set screws which are in the guides for tightening up the shoe to the cross-head, and the other end to the board by a bolt—care being taken to so fit all the bolts that there will be no lost motion, and then see that the center on which the board vibrates is in the middle of its travel. Then make a hole in the vibrating board, near enough to the center of vibration to get the 4 in. of motion. Follow the directions previously given, for leading off the cord at right angles to the board when the piston is in the middle of its travel. In some cases it may be more convenient to suspend the vibrating board from a point over head. All cases cannot be described, but

each individual case has to be considered according to its situation and peculiar conditions.

All the time that you have been preparing these things for your motion, &c., it is presumed that the engine is in motion doing its regular daily duties. It should be a point with the skillful engineer never to hinder the manufacturing business to which an engine is attached, but to let it be known that he can make his examinations and indications without any hindrance to the proprietors. The engine must be stopped long enough to insert the Indicator cocks in the cylinder and connect the motion to the cross-head. The writer has done this repeatedly in three minutes. Now direct the engineer in charge to start up, and as the engine moves slowly see that your connections are all safe and right, and everything clear, then you can attach the Indicator to the cock on one end of the cylinder, by means of the screw coupling, and your cord to the source of its motion, and now you are ready to

FIX THE PAPER

on the paper cylinder. For this purpose remove the paper cylinder from the instrument; secure the lower edge of the paper, near the corner, by one spring, then bend the paper round the cylinder, and insert the other between the springs. The paper should be

long enough to let each end project at least half an inch between the springs. Take the two projecting ends with the thumb and finger and draw the paper down, taking care that it lies on the cylinder smooth and tight, and that the corners are even, then replace the cylinder. The paper should be of a good quality, without any ruling upon it. The pencil may be a No. 4, and whittled down so as to screw into the socket provided for it in the parallel motion. With the paper on, and the pencil properly pointed and in its place, the motion of the cord all right, and some reliable person to count the revolutions of the engine per minute, you may proceed to hook on the cord and

TAKE THE DIAGRAM.

First open the stop-cock fully and let steam into the Indicator, then turn it off in the direction which opens communication between the under-side of the piston and the atmosphere; apply the pencil to the paper and it will draw the atmospheric line. Then remove the pencil from the paper an instant while you open the cock fully again, and apply the pencil to the paper and take the diagram. You can hold the pencil to the paper during one revolution, or more, as you please. If the engine has a fixed cut-off and a constant load, and the steam keeps at the same pressure

it will trace the diagram nearly in the same line all the time; but if it is a variable cut-off, controlled by the action of a governor, and a variable load, it will rarely make two alike. The writer has cards taken from variable cut-off engines, where the pencil was kept to the paper for some time, that are nearly all covered within the area of the largest with the pencil markings, from the perfect vacuum line to the highest point reached. Now shut off the steam from the Indicator and unhook the cord, and take off the diagram by slipping it from under the springs, and note on the back of it as many of the following facts as you are in possession of, viz.:

The date, hour, and minute of taking the diagram.
The name of the owner, and which engine if he has more than one.
Which end of the cylinder.
The pressure of steam, as per guage in the boiler.
The number of revolutions per minute.
The diameter of the bore of the cylinder.
The length of stroke.
The scale of the Indicator.
The name of the builder of the engine.
The kind of valve.
The size of the steam and exhaust pipes.
Whether the throttle is wide open or not.

The kind of governor, if any.

On a condensing engine, the vacuum per gauge.

The temperature of the discharge.

The size and kind of the air pump, and how it is driven.

The highth of the barometer.

A description of the boiler.

The amount which the waste room in the clearance and passage would add to the length of the cylinder.

The amount of coal consumed per hour.

The temperature of the feed water, and the quantity used.

And any other special items that may appear important.

You can now take more diagrams from the same end of the cylinder, and then change the Indicator to the other end and take cards from there. The cards from both ends of the cylinder will not be alike; this is due, if there were no other cause, to the angularity of the connection rod which gives a higher rate of speed to the piston as the crank passes the semi-revolution the farthest from the cylinder. In a direct-acting engine, of from 15 to 33 per cent., the difference varying according to the degree of angular vibration of the connection rod. In beam-engines the highest rate of speed of

piston, from this cause, will be at the top, or when the crank is passing the lower semi-revolution. The reader will please take special notice of this on the pair of diagrams No. 7, taken from both ends of a cylinder of a direct-acting engine, the left hand diagram was taken from the out-end of the cylinder, or the end farthest from the crank, where the slow motion is found; the right hand diagram was taken from the crank end, or the end nearest to the crank, where the fast motion is found, and you will notice the difference. The steam rose about 4 pounds higher than in the other, and the piston moving rapidly caused the pressure to fall about 5 pounds lower than the other diagram to the point of exhaust. The extra velocity of the piston also affected the counter-pressure line, which does not fall so low as the left hand diagram, and makes the right hand diagram more pointed than the left. The slower motion of the piston on the left-hand diagram maintains the pressure on the expansion line, and gives more time for the exhaust, which carries the counter-pressure line lower and makes a fuller and better shaped diagram. The average effective pressure on the left hand diagram is 36 pounds per square inch, and on the right hand diagram 31½ pounds. The steam on these diagrams is pretty badly wire drawn, on account of the throttle-valve being partly closed, and

the points of cut-off, although not well defined, are somewhat different in time—one following about $\frac{3}{10}$ of the stroke, and the other over $\frac{4}{10}$. These last named causes also affect the shape of the diagram, and, taken with the former, produce the result seen in Diagram No. 7.

If, now, you have taken what cards are necessary from both ends of the cylinder, shut the stop-cocks and take off the Indicator and lay it away in the box. Then stop the engine for about two minutes, take out the cocks and insert the plugs, and disconnect your temporary motion and have the engine got under way again at once, making no delay to the manufacture. Next, take care of your Indicator. The Indicator will not work well unless it is kept in good order. When used it becomes filled with water, which will rust and weaken the spring, and the steam often contains impurities and grit, some of which may lodge in the Indicator. Unscrew the cover of the cylinder case, and draw off the upper ferrule with the pencil movement and the piston and spring attached, empty the water from the cylinder, and clean and dry all the parts and replace them, oiling the cylinder and other parts with a few drops of the best oil. Wipe it up clean and lay it away in the box, and it will be ready for use the next time you want it; but if you neglect

to care for it as above, it will soon become weak in the springs and rusty and sticky, and finally fail to give any indications that can be relied upon.

WORKING UP THE DIAGRAMS.

TO ASCERTAIN THE HORSE-POWER OF THE ENGINE.

As has been previously stated in this work, on page 22, the horse-power of an engine is that used by Watt, viz., 33,000 pounds raised one foot high in one minute, or 33,000 foot pounds, and this is now employed as the unit of measurement of the actual horse-power of steam-engines, and the rule for calculating it is simply this:

RULE FOR CACULATING THE HORSE-POWER OF STEAM-ENGINES.

Multiply the mean effective pressure on one square inch of the piston in pounds, by the area of the piston in square inches, and that product by the speed of the piston in feet per minute, and divide by 33,000, the quotient is the horse-power of the engine. Example—You have an engine of say 10 inches diameter of bore of cylinder, and 2 feet length of stroke, and it runs 100 revolutions per minute, and you have 32 pounds mean effective pressure on one square inch of the piston, what

is the horse-power? Area of 10 in. piston $= 78\frac{54}{100}$ sq. in.; one revolution of a 2 ft. stroke is equal to 4 ft., which, multiplied by 100, gives 400 ft. as the speed of piston per minute, this, with the mean effective pressure given, makes out the requisite data

$$\frac{78.54 \times 32. \times 400}{33{,}000} = 30\tfrac{15}{33} \text{ horse-power,}$$

or,

78.54

multiplied by 32

15708

23562

2513.28

multiplied by 400

divided by 33,000) 1005312.00 ($30\frac{15}{33}$ the horse-power.

99

15

The above data may be found as follows: The area of any piston, by the use of the *engineers slide rule* (see advertisement at end of volume), by setting 78.54 on the C line, against 10 on the D line, then against any other diameter on D, is its area in square inches on C.* It may also be found in tables of areas.

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*In the book, descriptive of the engineers slide rule, there are full directions given for getting the horse-power of engines, and when it is once understood, and the data are given, the horse-power of any engine can be told in 10 seconds, the writer himself

The length of the stroke is easily measured, and this doubled and reduced to feet, and multiplied by the number of revolutions per minute, gives the speed of piston in feet per minute. Our mean effective pressure we may assume, or if we know the boiler pressure and the point of cut-off we may demonstrate mathematically the mean pressure by the use of *hyperbolic logarithms*, and when arrived at it will be an approximation to the actual facts.

THE ONLY MEANS KNOWN

to steam engineers to arrive at this mean effective pressure with certainty is by the "use of the steam-engine Indicator." The diagram shows the pressure on one square inch of the piston at all points of its stroke, and from this we must calculate the average or mean pressure. The piston of the Indicator is made of a diameter sufficient to give it an area of one half a square inch, and the springs are made of a tension suitable to make them agree with a scale corresponding to which they are marked, and with this scale the vertical highth of the diagram is measured, and its figures represent the pressure on one square inch of

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can do this, and will be pleased to satisfy any incredulous person on this point who will favor him with a personal interview and put the question and give the data.

the steam-engine piston. Now, the average mean pressure is found in this way: Divide the diagram into any number of equal parts (the writer usually uses ten), by lines drawn perpendicular to the atmospheric line. Then draw lines parallel with the atmospheric line, in spaces of five pounds, according to the scale of the Indicator, up as high as the boiler pressure (which record you will find on the back of your diagram) and below as far as the perfect vacuum line.

IF IT IS A CONDENSING ENGINE,

the diagram should be partly below the atmospheric line.* It is of no consequence what the character of the diagram may be—whether it is high up or low down on the lines you have just drawn, or whether it is most wasteful like diagram No. 11, or economical like No. 12 — for the purpose of ascertaining the power exerted we have merely to measure its included area, and so get the mean pressure on one square inch during the stroke which this area represents. The

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* I have diagrams taken from a condensing engine on which the counter-pressure line is 5 pounds *above* the atmospheric line at its lowest point, when, at the same time, there was 18 in. of vacuum in the condenser. You may ask, how could a man afford to run such an engine as that? He didn't know it, and supposed it was all right until these cards were taken, when the fact was shown that the engine was wasting 76 per cent. of its steam.

writer uses a planimeter and measures the area of the diagram first above the atmospheric line, next below it; adding the two areas together and divide this sum by the extreme length of the diagram, the quotient is the mean highth, which, multiplied by the scale of the Indicator, gives the mean pressure. But a plain and simple way of doing is to measure very carefully the highth in each of the ten vertical divisions and add them all together, and point off the right hand figure. This will give you the mean highth, which again multiplied by the scale gives the mean pressure in pounds per square inch. Thus you have all the data from which you can calculate the horse-power of the engine, according to the rule previously given.

THEN THE BACK PRESSURE

can be found by measuring. If it is a condensing engine, the distance between the perfect vacuum line and the counter-pressure line, or if it is a high-pressure or non-condensing engine, by measuring the distance between the atmospheric line and the counter-pressure line.

THE PERFECT VACUUM LINE

will vary according to location and condition of the atmosphere, and for certain purposes the engineer

should note the highth of the barometer and locate the perfect vacuum line accordingly; but for the purposes of this book I have assumed 15 pounds as the perfect vacuum point below the atmospheric line, and divided the diagrams off into atmospheres of 15 pounds each.

THE CONSUMPTION OF STEAM.

For this purpose ascertain how much the clearance and steam passage way add to the length of the cylinder at one end, and add a proportionate quantity to the length of the diagram, by a line drawn perpendicular to the atmospheric line at the proper distance from the admission line. Then ascertain the point in the stroke at which the steam is released, and the pressure in the cylinder at that point. Multiply this pressure, measured from the line of perfect vacuum by the sectional area of the cylinder in square inches, and the product by the length of the stroke in inches up to the point at which the steam was released, including the addition for the clearance and passage way, and divide by 14.7 and the quotient will be the number of cubic inches of steam, at the pressure of the atmosphere, discharged from the cylinder at a single stroke. If the valves do not leak, and there is no water with the steam, the cubic contents of the cylinder, multiplied by the pressure at the point of cut-off, should equal the cubic

contents multiplied by the pressure at the point of exhaust, and in a compound engine the cubic contents of each cylinder, multiplied by the pressure at the point of exhaust, should give the same result. Multiply this by the number of strokes in an hour, and divide the product by 1728, to reduce the cubic inches to cubic feet, and the quotient again by 1700, to reduce the steam at atmospheric pressure to water, and the result will be the number of cubic feet of water used per hour. Multiply this by 62.5 for pounds, and divide the product by 8.33 for wine gallons. The supply of water to the boiler will need to be greater than the quantity thus ascertained, and the excess required will correspond with the loss from all sources, such as leakage, priming, blowing off, and radiation from the cylinder and pipes where the water of condensation does not flow back into the boiler. Having found in the foregoing manner the amount of steam consumed per hour, and reduced it to water in pounds, you can assume, if you please, that one pound of good coal will evaporate ten pounds of water per hour in a good boiler, and dividing by ten, will give you the pounds of coal consumed per hour, and if you know just how much is burned you can compare. Now, if you divide the pounds of coal by the horse-power found by the card, you will have the pounds of coal per horse-power

per hour, and if it is over three there can be a saving made on that engine by some means.

TO ASCERTAIN IF THE STEAM VALVES ARE TIGHT.

Draw the correct expansion line, and for this purpose, after having added the proper amount to the admission end of the diagram for clearance, divide the distance up to the point of cut-off into any number of equal parts. In our theoretic diagram No. 1, it is divided into two parts. Then continue spaces of the same distance to the end of the diagram, and if it does not come out even make one line beyond the diagram. Draw the perfect vacuum line at the proper distance below the atmospheric line, and measure from it with the Indicator scale to the steam line. Number the vertical lines, commencing at the first one from the admission end, and if the point of cut-off comes, as in our diagram No. 1, at two, then to find the point where the curve cuts the third line divide the number of pounds found upon the Indicator scale as above by three and multiply the quotient by two, and the product is the highth of the intersection measured with the scale from the perfect vacuum line as before. Mark it, and proceed to the fourth line. Now divide by four, and multiply by two, and mark the point on the fourth line, and so on to the end, always dividing by the number of the line where

you are seeking the location of the curve, and multiplying by the number of the line at the point of cut-off. Then trace in the curves—the more numerous the divisions the more accurate will have been the work. Having drawn this correct expansion curve, see if the diagram terminates very much above it; if it does, the steam valves probably are not tight. If the diagram falls below it, then the piston or exhaust valves leak. Having the diagram drawn in this manner, or worked up, you have found from it the pressure on the piston at every point of the stroke, the average mean pressure throughout the stroke, and the horse-power expended, also the back pressure, or the amount of power expended in forcing out the exhaust, how near the boiler pressure is reached in the cylinder, at what time in the stroke the highest pressure is reached and how well it is maintained, at what point and what pressure the steam is cut off, whether it is cut off quickly or whether it is wire drawn, also at what point in the stroke the exhaust opened and closed, and the pressure at these points, also the pressure arising from compression of the exhaust, also the steam lead, the amount of steam consumed and water evaporated, and the amount of coal burned to evaporate that water, and if the steam and exhaust valves and piston are tight. The Indicator shows faithfully, and only

shows the pressure on one side of the piston in its forward and backward movement, and in doing this it has described a peculiar shaped figure. The causes which have determined that shape must be arrived at by a process of reasoning, and the ability to judge correctly of the causes which have produced a certain form is no mean attainment, and to the student of engineering nothing can be more profitable than the careful study of the diagrams contained in this work, as they have been taken from engines in actual use at no very remote date; and now let us refer to some of them and consider.

THE DIFFERENT LINES OF THE DIAGRAM.

THE POSITION OF THE LINES.

The atmospheric line is the horizontal line in all the diagrams at 0. The perfect vacuum line is the third line below 0, marked 15, strictly 14.7, more or less, according to the highth of the barometer. The admission line, diagram No. 1, is the vertical line at the left hand end. The steam line is the horizontal line at the top, and on this diagram is continued for $\frac{2}{10}$ of the stroke. The expansion line commences where the steam line ends, or at the point of cut-off, and in this case is a hyperbolic curve and continued to the end of

the diagram. The exhaust line is the short vertical line at the right hand end. The counter-pressure line in this diagram is the same as the atmospheric line. The compression line is not shown, but it is the ending of the counter-pressure line and the commencement of the admission line. The perfect vacuum line is very rarely drawn by the Indicator, but is drawn by hand, although the writer has diagrams where a very near approach to it is made.

ON DIAGRAM NO. 2,

beginning at the commencement of the stroke, at the right hand end, the admission line starts at 10 pounds pressure, and rises vertically to about 27 pounds, when the piston moves, after which the pressure rises a trifle until the piston has moved about $\frac{1}{10}$ its stroke, when the velocity of the piston increasing the pressure commences to fall and continues to fall to the point where the exhaust valve opens at about $\frac{98}{100}$ of the stroke. The steam in this diagram was cut off by lap on the valve at $\frac{75}{100}$, but it is not shown at all, and, strictly speaking, there is no expansion line in this diagram. It is all steam line, of very bad character, clear to the opening of the exhaust. The exhaust line continues from the point of its opening to the end of the stroke, falling at a small angle from the perpendicular until

the motion of the paper commences to return, and at this point begins the counter-pressure line, which falls away to the atmospheric line at the first tenth of the return stroke, and continues on the atmospheric line until it reaches the point of $\frac{9}{10}$ of the return stroke, when the valve closes the exhaust and the compression line commences and takes a diagonal course upward to 10 pounds pressure, to the point of commencement of the admission line, which is the point where we commenced our description of this diagram. The reader will have no difficulty in following these descriptions, as the diagrams are divided vertically into five pound spaces and longitudinally into ten divisions, each space representing $\frac{1}{10}$ of the length of the stroke of the engine.

DIAGRAM NO. 3,

taken from the same engine after an independent cut-off had been put upon it, shows a different form. The admission line commences at 5 pounds pressure and rises vertically to about 43 pounds, when the steam line commences and rises a little and falls again before the first tenth is reached, and continues to fall to the second tenth. This falling of the pressure, from the first to the second tenth, is caused by the gradual closing of the cut-off valve, which is fully closed at the second

tenth, and from here, in this diagram, commences the expansion line, which runs to the opening of the exhaust at $\frac{98}{100}$ of the stroke. The exhaust line here is nothing, being nearly horizontal and only $\frac{2}{100}$ of the stroke long. The counter-pressure line commences at the beginning of the return stroke, and falls away to about 1 pound above the atmospheric line, at the first tenth of the return stroke, and then follows parallel, or nearly so, to about $\frac{96}{100}$, when the exhaust closes and the compression line begins and runs to the five-pound point at the place of beginning.

DIAGRAM NO. 4.

The admission line commences at the left hand end, at the point of 10 pounds pressure, and rises vertically to about 23 pounds, when the piston advanced about $\frac{2}{100}$ of the stroke and the pressure rose during the same time to about $26\frac{1}{2}$ pounds, and from that point commences to fall and falls to about 16 pounds at $\frac{8}{10}$ of the stroke, when the main valve closed, which caused a slight fall of pressure to the point of exhaust which is not very marked; but the exhaust line falls vertically to the point of 5 pounds pressure when the counter-pressure line commences and falls gradually to $\frac{2}{10}$ of the return stroke, and then runs along at about 1 pound pressure falling slightly to about $\frac{92}{100}$, when

the compression line commences and raises the pressure to 10 pounds to the place of beginning.

DIAGRAM NO. 5

is similar to No. 3, but in this the cut-off is at about $\frac{27}{100}$ of the stroke. The horse-power developed, as shown by this diagram, is 31, and on No. 3 it was $29\frac{1}{2}$; the average mean pressure being on No. 5, $14.\frac{4}{10}$ pounds, and on No. 3, $14.\frac{1}{10}$ pounds per square inch.

IN DIAGRAM NO. 6

the engine did not get its steam until the piston had passed about $\frac{62}{100}$ of its stroke at about 78 pounds pressure, and then the cut-off closed it at about $\frac{85}{100}$, and the pressure fell off to 60 pounds, when the exhaust and counter-pressure line all went into one, and sneaked along down to 15 pounds above the atmosphere at the lowest point. Altogether it is about as bad a diagram as one ever need expect to see.

ON THE PAIR OF DIAGRAMS NO. 7.

First, the right hand one: The admission line commences at 35 pounds above the atmospheric line, the steam valve is behind time, and the piston moves on about $\frac{5}{100}$ of its stroke before the highest pressure, 55 pounds, is reached at about $\frac{1}{10}$ the stroke, when the pressure commences to fall and the steam-valve is

closed at about $\frac{3}{10}$ of the stroke. The steam expands to about 13½ pounds at the end of the stroke, at which point the exhaust opens and the counter-pressure runs down to 5 pounds below the atmosphere at $\frac{55}{100}$ of the return stroke and remains there until $\frac{7}{10}$ is reached, when the compression commences and the pressure rises to 35 pounds, the place where the admission line began.

THE LEFT HAND DIAGRAM.

The steam-valve opens for admission at a pressure of 44 pounds, and immediately the pressure falls to 34 pounds; then rises again at about $\frac{5}{100}$ of the stroke to nearly 50 pounds, and follows at that pressure for a little more than $\frac{1}{10}$, when the pressure commences to fall. When at $\frac{45}{100}$ it has fallen to about 45 pounds, the point where the steam-valve closes, the expansion line now runs to the end of the diagram and the exhaust opens and the pressure falls vertically for a short distance, when the counter-pressure commences and the pressure falls at $\frac{52}{100}$ of the return stroke to 6 pounds below the atmosphere, and keeps there until $\frac{65}{100}$ is reached, when compression begins and runs the pressure up above the point of admission to the point of beginning, forming the loop seen at the left hand end of this diagram.

DIAGRAM NO. 8.

In this diagram there seems to be no admission line; but starting at 50 pounds pressure, which has been reached by compression, the pressure falls at once to 20 pounds at about $\frac{3}{100}$ of the stroke. Then the piston of the Indicator recoils slightly, and falls again and crosses the compression line at about $\frac{11}{100}$, and falls to about $2\frac{1}{2}$ pounds; then rises again to 4 pounds, at about $\frac{12}{100}$, and from there gradually falls until it crosses the atmospheric line at $\frac{83}{100}$, and falls to a little more than 1 pound below the atmospheric line, to the point of exhaust at about $\frac{97}{100}$, when the atmosphere comes in and raises the pressure to a little more than 1 pound above the atmosphere, which gradually falls until $\frac{8}{10}$ of the return stroke is reached, when the compression begins and carries the pressure up to 50 pounds, the place of beginning. In fact when this card was taken the engine was run by the compression. In this stroke it seems not to have taken any live steam at all, which is a characteristic of this engine. When the speed is up, and the steam is not wanted, it shuts it all off; and when it takes steam, what is taken is right up to boiler pressure. The writer has seen this engine supersede an ordinary slide-valve engine, and save 75 per cent. of the fuel required by the old engine, which, after all, was not very old, having been run only about two and

a half years. This diagram was taken at a speed of 225 revolutions per minute. (See page 18.)

DIAGRAM NO. 9.

The admission line commences at the right hand end, at a point about 6 pounds above the atmosphere, and rises vertically to a little above 35 pounds when the piston moves, the pressure still rising slightly until about $\frac{5}{100}$ of the stroke is reached, when the cut-off valve commences to close and the pressure commences to fall and falls to the point at which the cut-off is closed—in this case, $\frac{13}{100}$ of the stroke. It is slightly noticeable on the diagram. Then expansion commences, and the pressure continues to fall to 4 pounds at $\frac{57}{100}$ of the stroke, when the cut-off passes by the opening in the main valve and admits steam to the cylinder the second time, the pressure rising gradually to 23 pounds at $\frac{9}{10}$ of the stroke and remaining until the exhaust opens at $\frac{97}{100}$, the exhaust line running vertically down to 10 pounds, when the counter-pressure commences and the pressure falls to 1 pound at the first tenth of the return stroke, and gradually approaches the atmospheric line until the compression commences at $\frac{96}{100}$ of the return stroke and runs the pressure up to 6 pounds to the place of beginning. This card shows a development of $28\frac{1}{2}$ horse-power, and the

cut-off valve was set to cut off the steam at 2 inches from the commencement of the stroke. The cut-off was then adjusted so as to cut off at 3 inches, when

DIAGRAM NO. 10

was taken. This is a tolerably good diagram, and is so similar to others that have been described that it need not be explained at this time. It shows a development of 29$\frac{3}{4}$ horse-power, which is 1$\frac{1}{4}$ more horse-power than No. 9, with over 50 per cent. less steam.

DIAGRAM NO. 11

is an aggravated case of wire-drawing. (See page 19.) The admission line commences at the left hand end, at about 4 pounds below the atmospheric line, and rises vertically to 25 pounds, and this pressure is continued to about $\frac{12}{100}$ of the stroke when the pressure commences to fall and falls to 7 pounds above the atmosphere at $\frac{8}{10}$ of the stroke, when the valve is closed by lap; the pressure still further falls to 2$\frac{1}{2}$ pounds at the opening of the exhaust at almost the end of the stroke, and the pressure falls vertically to 3 pounds below the atmosphere when the counter-pressure commences and the pressure falls gradually to 8 pounds at $\frac{96}{100}$ of the return stroke, when compression commences and carries the pressure up to 4 pounds below the atmosphere, to the

place of beginning. The point of cut-off could not be determined at all if it were not known. This is a fair specimen of a diagram that could be taken from thousands of engines that are running in this country to-day, and in every such case they are wasting fuel for their owners to from 25 to 75 per cent. Diagrams of this character have been dismissed by experts, as subjects not fit for consideration; but whenever the writer meets such diagrams he will endeavor, by all means in his power, to vanquish them and bring about such changes as will make the engine take a diagram that will show a good degree of economy and not a flagrant waste. In this case the engine had a thorough overhauling, and a new cylinder and valve gear, and passages better adapted to its wants. When it had been got in good running condition

DIAGRAM NO. 12

was taken. This is a good diagram. Commencing at the right hand end the admission line starts at 5 pounds above the perfect vacuum line, and rises vertically to 34 pounds, when, as the piston moves, the pressure rises to 35 pounds and the steam line follows to about $\frac{7}{100}$ of the stroke, when the valve closes and the expansion line commences; and here you may see a first-class expansion line. The steam expands to 5 pounds below the atmosphere, at the end of the

stroke, when the exhaust opens and the counter-pressure commences, and the pressure falls gradually to nearly the perfect vacuum line at $\frac{97}{100}$ of the return stroke, when the compression carries the pressure up to 5 pounds above the perfect vacuum line, to the place of beginning. That engine cannot be improved upon very much. (See page 20.)

DIAGRAM NO. 13.

In this diagram the admission commences at 1 pound above the atmosphere and the piston moves at the same time. The pressure rises gradually to 55 pounds at $\frac{1}{10}$ of the stroke, and at $\frac{2}{10}$ it is up to 57 pounds; the admission line may be said to have ended at $\frac{1}{10}$. The pressure in the boiler at the time this card was taken was 60 pounds, so it will be seen that it is a first-class diagram, excepting in the time of the movements of the valves. The steam line is continued with a slight fall of about 1 pound to $\frac{67}{100}$ of the stroke, when the valve closes and the expansion line commences, and the steam expands to 35 pounds pressure at the end of the stroke, when the exhaust opens and the pressure falls at once to 24 pounds, when the counter-pressure line commences and the pressure falls to about 1 pound at $\frac{4}{10}$ of the return stroke and continues nearly parallel with the atmospheric line to the

end at 1 pound above the atmosphere, the place of beginning. There is no compression line on this diagram.

DIAGRAM NO. 14

has been fully explained at page 21.

DIAGRAM NO. 15

was taken from the same engine that No. 13 was taken from, with a condenser attached and working low-pressure. The admission line commences at the left hand end, at 10 pounds below the atmosphere, and shows the steam-valve behind time nearly the same as No. 13. (This diagram was taken from the opposite end of the cylinder.) The pressure runs to 38 pounds above the atmosphere, at $\frac{6}{100}$ of the stroke, when the steam-valve closes and the expansion line commences, and the steam expands to 5 pounds below the pressure of the atmosphere when the exhaust opens and the counter-pressure commences and falls, at the first tenth of the return stroke, to nearly 10 pounds below the atmosphere, and runs back to the end of the stroke, at that highth, to the place of beginning. There is no compression line in this diagram. When this diagram was taken the vacuum, per gauge in the condenser, was 23 inches, which is equal to about 11½ pounds, and on the

diagram it is 10 pounds. A very fair result. (See page 22.)

DIAGRAM NO. 16

is another aggravated specimen of wire-drawing. The admission line commences at 2 pounds above the atmospheric line and rises vertically to 20 pounds, and from there, at a small angle, reaches 27 pounds, when the piston of the Indicator recoils and rises again, and at $\frac{1}{10}$ the stroke is at about 19 pounds pressure when it commences to fall and falls in a sickly manner to the point of exhaust at nearly the end of the stroke, the pressure having fallen to 5 pounds above the atmosphere. The exhaust line runs down the pressure to about $2\frac{1}{2}$ pounds, when the counter-pressure line commences and the pressure falls to a little less than 1 pound at $\frac{15}{100}$ of the return stroke, and remains there until $\frac{97}{100}$ of the return stroke is reached and the compression line commences and carries the pressure up to 2 pounds, to the place of beginning. This engine had a slide-valve, an independent cut-off, and a throttle governor; but you cannot tell from the diagram where the cut-off or the main valve closed. The cut-off closed at $\frac{38}{100}$ of the stroke, and the main valve probably closed at about $\frac{87}{100}$. The counter-pressure line is fair; but upon the whole it is a bad diagram. (See page 22.)

GENERAL REMARKS.

THE CONSTRUCTION OF THE INDICATOR.

The Indicator was the invention of Watt, who attempted to keep the invention for his own exclusive benefit, as he was a large manufacturer of engines, and by indicating them in private was enabled to so improve upon them as to give him an advantage over other makers who knew nothing of his cherished secret; but it was impossible for him to keep it secret, and it became known to the trade and was manufactured and sold. Wm. McNaught, of Glasgow, manufactured one form, which consisted of a paper cylinder, similar to the one shown in this work (see frontispiece), which received its motion from a cord attached to the engine, as described in this work, page 29. The steam-cylinder of these Indicators was necessarily of great length, in comparison with the one shown in this work, and the springs also had to be correspondingly long, and their weight, with the piston and pencil attachment, when put in motion suddenly, produced a momentum which would carry the pencil up past the true pressure, and then it would recoil and vibrate up and down in such a violent manner as to produce a figure upon which very little reliance could be placed, except for slow motions and low pressure of steam, when

15 pounds above the atmosphere was all that was used, and a piston speed of 240 feet per minute; but when a pressure of 100 pounds became common, and cut-off engines were introduced, and speeds of piston of 400 to 600 and 800 feet per minute, and motion of 200 to 300 revolutions were used, the above described Indicators were not to be relied upon. In fact it was impossible to indicate one of these high-speed and high-pressure engines with them. There was an Indicator constructed by the firm of Maudslay & Field, on the same general principles as have been described, but differing from McNaught's in outside appearance.

THE INDICATOR USED BY THE WRITER

is know as "*Richards' Parallel Motion Indicator*," and was invented by Mr. C. B. Richards, of Hartford, Ct. It has been manufactured in London by Elliott Brothers, which fact has given rise to the notion in some places that it is an English invention. They are manufactured in this country by the "*American Steam Gauge Co.*," of Boston, Mass. The invention by Mr. Richards of this Indicator, may justly be said to be one of the great improvements of the age; as for the reasons previously given the old style of Indicators are wholly useless on the great majority of engines of the present day. This Indicator, with proper

management, will work equally well on fast or slow speeds, on high or low pressures, as is shown by the diagrams in this work. They have been used successfully in England and in this country, on locomotives making their regular trips with express trains on the roads, which is sufficient evidence of the reliability of the instrument. The difference between this and the old style of Indicator consists in this, having a short and strong spring and a short movement of piston, both are made very light with considerable section of cylinder, and an arrangement of levers for multiplying the motion of the piston, and a parallel motion for carrying the pencil, in such a manner that the diagram is described in the same way and about the same size as by the old style of Indicator. It is in every respect a first-class instrument.

THE IMPORTANCE OF INDICATING ENGINES.

There probably never was a time in the history of the manufacturing interests of this country when the importance of indicating steam-engines was greater than it is now. Manufactures are depressed, fuel is high, and a giant combination has its mercenary hand on the principal coal-fields of this country, and when it would seem that the laboring classes and manufacturers, many of whom are out of business, should be supplied

with fuel at fair rates, the price of coal has been steadily advanced from the first opening of the season to the present time. What is the remedy for this? Economy in the use of fuel is certainly one remedy. How shall we economize further? Every manufacturer knows precisely how much coal he is using—he has good reason to. He has to pay the bills. Nothing could furnish better evidence to his astonished senses than those periodically recurring coal bills, with manufactured goods falling, and the price of coal rising. He may know positively the amount of coal used, but very few know the amount of power which they derive from that amount of coal. Let every manufacturer who would economize in his coal expense have his engines examined by some expert engineer with an Indicator, and see how much power he is using, and then let him see what amount of coal he is using per horse-power per hour. It should not exceed 3 pounds, and might be considerably less. The writer has indicated several engines recently that have run as high as 9 pounds, 9½ and 12 pounds, and in one instance as high as 18 pounds per horse-power per hour. What price ought any man to pay for such an engine as that? Why, it is dear at a gift. The writer knows of engines that have wasted $100,000 worth of fuel, where the original cost of the engine did not exceed $25,000.

Who will attempt to say that such an engine would not have been dear at a gift? And this is not an isolated case. There are many such. A great majority of the engines in this country to-day are using twice as much coal per horse-power per hour as would suffice to furnish the same power with a first-class machine. If an engine will not furnish one horse-power with the consumption of 3 pounds of coal per hour, then the quicker it is thrown away the better for the party having the coal bills to pay. But a man has on his hands an engine, and he is advised that it is wasting his fuel to the extent of 25, 50, or perhaps 75 per cent., and he thinks he cannot afford to make any change, what can he do? There can be something done with it. Perhaps a new cylinder, or a new valve-gear, or condenser (if it was high-pressure). That will cost him less at first than he would have to pay for fuel at the same time, which might be saved by the change the first year, and when it is thus changed, although he may not have a strictly first-class engine in every particular, he will be in a condition to save money enough to buy one with when the times are more propitious. But people have been humbugged. They have tried appliances that have been promised to save a certain per cent. and they have failed. One man has a frictionless valve, another a

balance-valve, another a patent packing, another a self-regulating damper, another a feed-water heater, and a multiplicity of other things, all of which are first-rate in their proper places. And the venders of these patents will very deliberately tell you that they will save 25 per cent. Now, does any sane man believe that 25 per cent. of the power of a twenty horse-power engine is expended in driving a slide-valve in its worst form? By all means have a balance-valve; but do not expect 25 per cent. saving from that source alone. If you do, you will be disappointed. I know of one engine that was fitted with a frictionless valve, and a saving of 25 per cent. claimed for it, and I also know that the frictionless arrangements lie in the scrap-box in that engine-room at the present time. The thing may have had merit in it, but too much was claimed for it, and it has fallen into disuse. Many things have turned out in a similar manner. Get an honest man, that is competent to indicate your engines — one that will report all the facts which he finds, and advise what to do under the circumstances—and when you are advised of the true state of the case, then you can act upon it when you see fit. The engine which diagram No. 11 was taken from had been indicated before, but the person employed, if he knew how bad it was, did not advise the proprietors of the waste of steam going on

there. The most charitable construction that can be put upon it is, that he didn't know a good card from a bad one. I trust the reader is now fully impressed with the fact, that before a discussion of the economical merits of any given engine can be entered upon, we must first know what its comparative economy is, and for this purpose we will assume as a starting point 3 pounds of coal as sufficient for one horse-power per hour. Now, is our engine using more, or less than this? I have read of engines being run with less than 2 pounds of coal per horse-power per hour, but I have never seen one that I know of. I have seen a number using from 9 to 18 pounds per horse-power per hour. You know the amount of coal used, find out the horse-power and divide. And now let us examine the

THEORY OF THE STEAM-ENGINE.

THE STEAM-ENGINE

is a machine for extracting mechanical power from heat through the agency of water. Heat is one form of mechanical power, or, more properly, a given quantity of heat is the equivalent of a determinate amount of power; and as heat is capable of producing power, so power is capable of producing heat. The nature of the medium upon which the heat acts in the production

of power—whether it be water, air, metal, or any other substance—is immaterial, except in so far as one substance may be more convenient and manageable than another. But, with any given extremes of temperature, and any given expenditure of heat, the amount of power generated by any given quantity of heat will be the same whatever be the nature of the substance on which the heat is made to act in the generation of the power. And just in proportion as power is generated will heat disappear. We cannot have both the heat and the power; but as one is transformed into the other, so will the acquisition of one entail a proportionate loss of the other, and this loss cannot possibly be prevented. It has been explained previously in this work that, as in all cases in which power is produced in a steam-engine, there must be an excess of pressure on the steam side of the piston, or, in other words, the steam pressure must be greater than the counter-pressure; so in all cases in which power is produced in any species of caloric engine, there must be a difference of temperature between the source of heat and the atmosphere or condenser. The amount of this difference will determine the amount of power, up to a certain limit, which a unit of heat will generate in any given engine. But, as the mechanical equivalent of the heat consumed in heating one pound of water to 1 deg. Fahrenheit would,

if utilized without loss, raise a weight of 772 pounds one foot high, it will follow that in no engine can a greater performance be obtained than this, whatever difference of temperature we may assume between the extremes of heat and cold. A weight of 772 pounds, raised one foot high for 1 deg. Fahrenheit thermometer, is equivalent to 1389.6 pounds raised one foot for 1 deg. Centigrade thermometer; but for convenience the term foot-pound is very generally employed to denote the dynamical unit, or measure of power expressed by a weight of one pound raised one foot high. A horse-power, an actual or indicated horse-power, is a dynamical unit, expressed by 33,000 pounds raised one foot high in one minute—or 550 foot-pounds per second, 33,000 foot-pounds per minute, 1,980,000 foot-pounds per hour. This unit takes into account the rate of work of the machine.

HEAT.

There are three forms of heat—Sensible Heat, Latent Heat, and Specific Heat.

Sensible Heat—Is heat that is sensible to the touch, or measurable by the thermometer.

Latent Heat—Is the heat which a body absorbs in changing its state from solid to liquid, and from liquid

to aëriform, without any rise of temperature; or it is the heat absorbed in expansion.

Specific Heat—Is an expression for the relative quantity of heat in a body, as compared with that in some other standard body of the same temperature. There is a constant tendency in hot bodies to cool, or to transfer part of their heat to surrounding colder bodies; and contiguous bodies are said to be of equal temperature when there ceases to be any transfer of heat from one to the other.

The most prominent phenomena of heat are, expansion, liquefaction, and vaporization.

DIFFERENCE BETWEEN TEMPERATURE AND QUANTITY OF HEAT.

It is evident that two pounds of boiling water have just twice as much heat in them as one pound; but it does not follow, nor is it the case, that two pounds of boiling water, at 212 deg., contain twice the quantity of heat that is contained in two pounds of water at 106 deg. Experiment shows, that when equal quantities of water, at different temperatures, are mixed together, the resulting temperature is a mean of the two. Thus, if a pound of water, at a temperature of 200 deg., be mixed with a pound of water at 100 deg., we have two pounds

of water resulting therefrom at a temperature of 150 deg. But, before we could suppose that a pound of water at 200 deg. has twice the quantity of heat in it that one pound has at 100 deg., it would be necessary to conclude that water at 0 deg., or zero, has no heat in it whatever. This is by no means the case, as temperatures much below zero have been experimentally arrived at, and even naturally occur in northern latitudes. One pound of ice, at a temperature below zero, rises in temperature by each successive addition of heat, until it attains the temperature of 32 deg. when it begins to melt; and, notwithstanding successive additions being made to its heat, its temperature refuses to rise above 32 deg. until liquefaction has been completed. As soon as all the ice has been melted, the temperature of its water will continue to rise with each successive increase of heat, until the temperature of 212 deg. has been reached, when the water will boil, and all further additions to the heat will be expended in evaporating the water or in converting it into steam. Although a pound of water, in the form of steam at atmospheric pressure, has only the same temperature as a pound of boiling water, it has a great deal more heat in it, as is shown by the fact that it will heat to a given temperature a great many more pounds of cold water than a pound of boiling water would.

ABSOLUTE ZERO.

The foregoing considerations lead naturally to the inquiry whether, although bodies at the zero of Fahrenheit's scale are still possessed of some heat, there may not, nevertheless, be a point at which there would be no heat whatever, and which point constitutes the true and absolute zero. Such a point has never been practically arrived at. But the law of elasticity of the gases, and their expansion by heat, leads to the conclusion that there is such a point, and that it is situated 461.2 deg. Fahrenheit below the zero of Fahrenheit's scale, or that it is – 461.2 deg. Fahrenheit – 274 deg. Centigrade, or – 219.2 deg. Reaumur. Prof. Rankine has shown that, by reckoning temperatures from this theoretical zero, at which there is supposed to be no heat and no elasticity, the phenomena dependent upon temperature are more readily grouped and more simply expressed than would otherwise be possible.

FIXED TEMPERATURES.

The circumstance of the temperatures of liquefaction and ebullition being fixed and constant, enables us to obtain certain standard or uniform temperatures to which all others may easily be referred. One of these is the melting point of ice, and another is the boiling point of pure water under the average atmospheric

pressure of 14.7 pounds on the square inch, or 2116.8 pounds on the square foot, or under the pressure of a vertical column of mercury 29.922 inches (practically 30 inches) high, the mercury being at the density proper to the temperature of melting ice.

THERMOMETERS—HEAT TO MEASURE.

Thermometers measure temperatures by the expansion which a certain selected body undergoes from the application of heat. Sometimes the selected body is a solid, as a rod of brass or platinum; sometimes a liquid, as mercury or spirits of wine; sometimes gas, air, or hydrogen. In a perfect gas the elasticity is in proportion to the compression, whereas in an imperfect gas—such as carbonic acid, which may be condensed into a liquid—the rate of elasticity diminishes as the point of condensation is approached. Every gas approaches more nearly to the condition of a perfect gas the more it is heated and rarefied, but an absolutely perfect gas does not exist in nature. Common air approaches sufficiently to the condition of a perfect gas to be a just measure of temperatures, by its expansion. Air and all other gases expand equally with equal increments of temperature; and it is found experimentally that a cubic foot of air, at the temperature of melting ice, or 32 deg., will form 1.365 cubic feet of the same pressure at the

temperature of boiling water, or 212 deg. Thermometers are not generally constructed with air as the expanding fluid, except for the measurement of very high temperatures. The most common kind of thermometers consist of a small glass bulb filled with mercury, and in connection with a capillary tube. The thermometer commonly used in this country is Fahrenheit's thermometer, of which the zero, or 0, of the scale is fixed at the temperature produced by mixing salt with snow; and which temperature is 32 deg. below the freezing-point of water. The Centigrade thermometer is that commonly used on the continent of Europe; and it is graduated by dividing the distance between the point where the mercury stands at the freezing-point of water and the point where it stands at the boiling-point of water, into 100 equal parts. On this thermometer the zero is at the freezing-point of water. Another thermometer, called Reaumur's, has its zero at the freezing-point of water, and the distance between that and the boiling-point is divided into eighty parts. Hence, 80 deg. Reaumur are equal to 100 deg. Centigrade and 180 deg. Fahrenheit. Water, in common with melted cast-iron, melted bismuth, and various other fluid substances, the particles of which assume a crystalline arrangement during congelation, suffer an increase of bulk as the point of congelation

is approached, and expands in solidifying. But as soon as any of these substances become solid, it then contracts with every diminution of temperature. Water, in freezing, bursts by its expansion any vessel in which it may be confined, and ice, being lighter than water, floats upon water. So, also, for the same reason, solid cast-iron floats on melted cast-iron. The point of maximum density of water is 39.1 deg. Fahrenheit, and between that point and 32 deg. the bulk of water increases by cold. A cubic foot of water at 32 deg. weighs 62.425 pounds, but a cubic foot of ice at 32 deg. weighs only 57.5 pounds. There is, consequently, a difference of nearly 5 pounds in each cubic foot between the weight of ice and the weight of water.

COMPRESSION AND EXPANSION OF GASES.

When a gas or vapor is compressed into half its original bulk, its pressure is doubled; when compressed into one-third of its original bulk, its pressure is trebled; when into one-fourth, it is quadrupled; and generally the pressure varies inversely as the bulk into which the gas is compressed. So if the volume is doubled the pressure is made one-half of what it was before—the pressure being in every case reckoned from 14.7 pounds below the atmosphere, or

from a perfect vacuum. Thus, if we take the average pressure of the atmosphere at 14.7 pounds on the square inch, a cubic foot of air, if allowed to expand twice its bulk by being placed in a vacuum measuring two cubic feet, will have a pressure of 7.35 pounds above a perfect vacuum, and also of 7.35 pounds below the atmosphere; if the cubic foot of air be compressed into a space of half a cubic foot, the pressure will become 29.4 pounds above a perfect vacuum and 14.7 above the atmosphere, or will be equal to a pressure of two atmospheres. This law was first investigated by a Frenchman, by the name of Mariotte, and is called Mariotte's law of gases. A cubic foot of air at 32 deg. becomes 1.365 cubic feet at 212 deg., the pressure remaining constant; or if the volume be kept constant, then the pressure of one atmosphere at 32 deg. becomes 1.365 atmospheres, or a little over $1\frac{1}{3}$ atmospheres at 212 deg. These two laws, which are of the utmost importance in all physical researches, it is necessary fully to understand and remember. The rates of expansion and compression for each gas are not precisely the same, but the departure from the law is small and need not be discussed here.

LIQUEFACTION.

Solidity is an accident of temperature, for there is reason to believe that there is no substance in nature that cannot be melted and even vaporized by the application of powerful heat. There are two incidents attending liquefaction that are important: The first is, that the liquefaction of the same substance always takes place at the same temperature, and the melting-point can be used as an index of temperature. The second is, that during liquefaction the temperature remains fixed, the accession of heat which has been received during the process of liquefaction being consumed or absorbed in accomplishing the liquefaction, or, in other words, it has become latent. This heat is given out again in the process of solidification. Water deprived of air, and covered with a thin film of oil, may be cooled to 20 deg. or 22 deg. below the freezing-point; but on solidification the temperature will rise to the freezing-point. Each substance has, under ordinary circumstances, its own melting-point; ice melting at 32 deg., and in melting absorbs as much heat as would raise the temperature of the same weight of water 142.65 deg., or as would raise 142.65 times that weight of water one degree; but, notwithstanding this accession of heat, the ice, during liquefaction, does not rise above 32 deg. If the heat

employed to melt ice was applied to heat the same weight of ice-cold water, it would heat it to the temperature of 174.65 deg., or 142.65 deg. added to 32 deg. the heat of the water when the heat was first applied. When there is no external source of heat from which the heat which becomes latent in liquefaction can be derived, and the circumstances are, nevertheless, such as to cause liquefaction to take place, the heat which becomes latent is derived from the substances themselves, and correspondingly lowers their temperature. Thus, when snow and salt are mixed together, the snow and salt are dissolved; but as in melting they absorb heat, and as there is no external source from which the heat is derived, the temperature of the mixture falls very much below that of either of the substances before mixing. So, also, when saltpetre and other salts are dissolved in water, cold is produced; and on this principle the freezing mixtures are compounded which are employed to produce artificial cold in warm climates.

VAPORIZATION.

The first phenomenon of the application of heat to a solid substance is to expand it, the next to melt it, and a further application converts it from a liquid into a vapor or gas. The point at which

increase of heat, instead of raising the temperature, is absorbed in the generation of vapor, is called the boiling-point of the liquid. Different liquids have different boiling-points under the same pressure, and the same liquid will boil at a lower temperature in a vacuum, or under a low pressure, than it will under a high pressure. As the pressure of the atmosphere varies at different altitudes, liquids will boil at different temperatures at different altitudes, and the height of a mountain may be approximately determined by the temperature at which water boils at its summit. Vapors are saturated gases, or gases are vapors surcharged by heat. Steam is the saturated vapor of water, or it is a thin, elastic, invisible fluid that water is converted into by the continued application of heat; and if any of the heat be withdrawn from it, a portion of the water is precipitated or condensed. That which is generated, after the boiling-point is reached and the water is in ebullition, is called steam; and that which is formed below the boiling-point, while the surface of the water is quiet, is called vapor—a distinction with a very slight difference. Surcharged or superheated steam resembles gas in its qualities, and a portion of the heat may be withdrawn from it without producing the precipitation of any part of its constituent water. Hence the importance of super-

heating steam, and carrying the heat up above the temperature due to that pressure; then, what heat is lost by radiation, as the steam passes through the pipes to the cylinder, can be spared from it without any condensation taking place, and the steam entering the cylinder will not carry much water with it. The writer believes that surcharged steam is also responsible for explosions in many instances. Some people will maintain that water in a steam-boiler never boils; but every one will agree with me that water boils in an open vessel, and, consequently, under a pressure of one atmosphere, and to that pressure is due (if the water is fresh) 212 deg. of sensible heat, and when two atmospheres of pressure are reached there is due to that pressure a temperature of about 250 deg. Now, when this temperature and pressure are reached, and the heat is properly distributed alike through the mass of steam and water, the water will boil just as certainly as it does under one atmosphere, or in an open vessel where all may see. And, as in an open vessel, if the heat becomes excessive, the pressure remaining constant, the water will boil more violently, so, under a pressure of two atmospheres, in a closed vessel, if the heat exceeds what is due to that pressure, the water will boil violently, and if the heat falls below what is due to

that pressure, then the steam-pressure preponderates and holds the water down as it were, and the ebullition ceases until the heat recovers or the pressure falls. What is true of one or two atmospheres is true of all pressures. This is one cause of priming, which occurs, as all steam-engineers know, most frequently upon engines whose boilers have too little steam-room, and when the water is high in the boiler, thus reducing the steam-room to its minimum and the engine is running fully loaded, and making large demands for steam upon the boiler, the pressure is thereby reduced below what is due to the temperature and the conseqence is very violent ebullition, so much so that the water is carried over into the cylinder at every pulsation of the engine and sometimes out of the safety-valve. I have seen the water priming twenty feet high out of a safety-valve pipe. Does any one suppose the water in that boiler was not boiling? So far, we have considered more particularly excess of heat in the water, now let us look at excess of heat, under certain conditions, in the steam. To superheat steam for useful purposes which have been mentioned, it should be done in a vessel or some portion of the generator somewhat (though slightly) removed from the water; or steam from several boilers may be made to pass through one common super-

heater on its way to the engine, thus being entirely removed from the generators, which is doubtless the best way. But suppose we have superheated or surcharged steam in an ordinary cylindrical boiler, the heat in the water is not up to what is due to the pressure of the steam and the surface of the water ceases ebullition. This may occur from stopping the engines, thereby suddenly raising the pressure, and perhaps at about the same time fresh coal has been put upon the fire, which aids in lowering the temperature just as the pressure from the previous cause is increasing. The foregoing will be seen to be an anomalous but by no means an impossible condition of affairs. Now, suppose the fire-line on the boiler-side is high and the water low, the steam receives additional heat, making matters worse, until it becomes excessively dry, dessicated, or surcharged steam, the appearance of which, if the upper water-gauge was opened, would be very blue—more resembling gas than steam—and in this condition it is perfectly harmless; it has not the tension of steam at much lower temperature, but it has a great excess of heat. Now, how can an explosion occur? Start the engine, and the steam commences to move off; circulation of the water commences, and every particle of this harmless dry steam at once seizes upon all the water

it can take up, suddenly becoming ordinary steam of somewhat less temperature, but enormously increased in density and pressure, with what effect upon the boiler depends entirely upon the strain it is capable of bearing without rupture. Suppose the heating of the side in contact with the steam to have reached 400 deg.; fully saturated steam, at this temperature, will assume a pressure of about 215 pounds per square inch above the atmosphere—a pressure quite equal to account for many of the disastrous explosions on record. Many steamboats have stopped at a wharf, and been started away again only to make a very few revolutions and explode their boilers, scattering destruction on every side. Stationary engines, too, in many instances, have had their boilers explode just after starting in the morning, or in the afternoon; and these explosions are marked with a violence akin to "*nitro glycerine.*" Juries of inquest talk about *gas* and *low water*, when the explosion has been reached by a series of perfectly natural causes. It is true the water has been low, but quite possibly not below the lower gauge at any time; and when the engineer, if he is living, tremblingly testifies, that before starting the engine he tried his water and found a full gauge at the lower cock, and again after starting in the brief interval that elapsed before the catastrophe, he tried it again,

and found water at the second gauge, and perhaps the third, he tells the *sacred truth*. But nine or more of those *gas* jurymen don't believe him. They say his nerves are affected, and he is desirous of screening himself; and of course no one else tried the gauges but him to disprove his statement. "But *it must be low water*." The very violence of the explosion proves that the boiler was perfectly sound, and the verdict is brought in accordingly: "Explosion caused by low water." It is best to provide for superheating without carrying the fire-line too high, and to have the water and steam-room in proper proportions, and to raise the safety-valve when getting up steam in the morning, and see that it raises at proper intervals if the engine is standing still for any length of time, however brief, and especially if carrying very high pressure. If the engine is standing still long at high pressure and the safety-valve does not blow, something is wrong. A boiler should not be left, when it is not doing any work, to superheat its steam and get all ready to go off the moment it is touched.

EXPANSION OF STEAM.

Under the head of compression and expansion of gases (page 74), the general law controlling compression and expansion was considered, and the same law

holding good for the expansion of steam, let us examine its practical utility in the steam-engine. When air is compressed into a smaller volume, a certain amount of power is expended in accomplishing the compression, which power, as in the case of a spring, is given back again when the pressure is withdrawn. If, however, the air, when compressed, is suddenly dismissed into the atmosphere, the power expended in compression will be lost, and there is a loss of power, therefore, in dispensing with that power which is recoverable by the expansion of the air to its original volume. Now, the steam in the boiler is in the condition of air already compressed, say to 60 or 75 pounds pressure, shall we wire-draw it down to 20 or 30 pounds to the cylinder, and thereby lose 50 to 75 per cent. of its power, or shall it be let into the cylinder at boiler-pressure, and cut off? The writer indicated an engine within the week this was written where the boiler-pressure was 75 pounds, and only 30 pounds was obtained in the cylinder. Unless the steam is worked expansively in the cylinder—which is done by stopping the supply from the boiler before the stroke is closed—there will be a loss of a certain proportion of the power which the steam would otherwise produce. If the flow of steam to an engine be stopped or cut-off when the piston has

reached the half-stroke, leaving the remainder of the stroke to be completed by the expanding steam, then the effect of that steam will be increased 1.7 times beyond what it would have been had the steam at half-stroke been dismissed without extracting more power from it; if the steam is cut off at one-third of the stroke, its mechanical effect will be increased 2.1 times; at one-fourth, 2.4 times; at one-fifth, 2.6 times; at one-sixth, 2.8 times; at one-seventh, 3 times; at one-eighth, 3.2 times. Referring again to diagram No. 12 we see by it that the steam was cut off suddenly at about $\frac{7}{100}$ of the stroke, and the expansion line is well defined and falls to 5 pounds below the atmospheric pressure at the point of exhaust. The $\frac{7}{100}$ referred to is a trifle over $\frac{1}{16}$ of the stroke. Thus, the reader may see that in actual practice we may exceed the figures given above, and I have seen 75 per cent. saving reached, as shown by the coal accounts.

In the following tables are given the average or mean pressure throughout the stroke, which would result from a given initial pressure and given fixed points of cut-off. In the first table the stroke is assumed to be divided into 8 parts and in the second into 10. The initial pressures are set down in the first column, and are given from 3 pounds to 20, advan-

cing by 1 pound; and from 20 to 100, advancing by 5 pounds; and from 100 to 200, advancing by 10 pounds.

EXAMPLE.

If steam be admitted to the cylinder at a pressure of 3 pounds per square inch, and is cut off at $\frac{7}{8}$ of the stroke and expands through $\frac{1}{8}$, the average or mean pressure during the whole stroke will be 2.96 pounds per square inch. In like manner, if steam at 3 pounds pressure per square inch was cut off at $\frac{1}{8}$ of the stroke, and expands through $\frac{7}{8}$, the average or mean pressure during the whole stroke would be 1.15 pounds per square inch.

TABLES OF PRESSURES

WHEN USING

STEAM EXPANSIVELY.

TABLE No. 1.

MEAN PRESSURE OF STEAM AT DIFFERENT RATES OF EXPANSION.

Initial Pressure in Pounds per Square Inch.	*Average pressure in pounds per square inch for the whole stroke.*						
	Points in the stroke at which the steam is cut off.						
	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
3	2.96	2.89	2.75	2.53	2.22	1.79	1.15
4	3.95	3.85	3.67	3.38	2.96	2.39	1.54
5	4.95	4.82	4.59	4.23	3.71	2.98	1.92
6	5.94	5.78	5.51	5.08	4.45	3.58	2.31
7	6.93	6.75	6.43	5.92	5.18	4.17	2.69
8	7.92	7.71	7.35	6.77	5.93	4.77	3.08
9	8.91	8.67	8.27	7.62	6.67	5.37	3.46
10	9.89	9.64	9.19	8.46	7.42	5.96	3.85
11	10.88	10.60	10.11	9.31	8.16	6.56	4.23
12	11.87	11.56	10.92	10.16	8.90	7.16	4.62
13	12.86	12.53	11.94	11.00	9.64	7.75	5.00
14	13.85	13.49	12.86	11.85	10.38	8.35	5.39
15	14.84	14.46	13.78	12.69	11.13	8.95	5.77
16	15.83	15.42	14.70	13.54	11.87	9.54	6.16
17	16.82	16.38	15.62	14.35	12.61	10.14	6.54
18	17.81	17.35	16.54	15.24	13.35	10.74	6.93
19	18.70	18.31	17.45	16.08	14.09	11.33	7.31
20	19.79	19.27	18.37	16.93	14.83	11.93	7.70

Initial Pressure in Pounds per Square Inch.	*Average pressure in pounds per square inch for the whole stroke.*						
	Points in the stroke at which the steam is cut off.						
	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
25	24.74	24.09	22.97	21.16	18.54	14.91	9.62
30	29.69	28.91	27.56	25.39	22.25	17.89	11.55
35	34.64	33.73	32.16	29.63	25.96	20.88	13.47
40	39.58	38.55	36.75	33.86	29.67	23.86	15.39
45	44.53	43.37	41.34	38.09	33.38	26.84	17.32
50	49.48	48.19	45.94	42.32	37.07	29.82	19.24
55	54.35	53.00	50.53	46.47	40.83	32.86	21.19
60	59.24	57.95	54.98	50.73	44.49	35.77	23.08
65	64.16	62.76	59.53	54.98	48.35	38.71	25.03
70	69.12	67.35	64.00	59.07	52.00	41.73	26.97
75	74.00	72.23	68.72	63.38	55.73	44.82	28.89
80	79.00	77.00	73.21	67.47	59.41	47.75	30.08
85	84.00	81.95	77.74	71.84	63.17	50.65	32.67
90	89.00	86.54	82.38	76.00	66.94	53.73	34.63
95	93.95	91.43	86.98	80.16	70.52	56.62	36.65
100	98.89	96.18	91.47	84.37	74.23	59.63	38.45
110	108.65	106.02	100.07	93.00	81.82	65.87	42.47
120	118.57	115.89	110.19	101.44	89.10	71.48	46.21
130	128.46	125.32	119.31	110.00	96.55	77.49	50.01
140	138.41	134.94	128.13	118.36	104.00	83.38	53.98
150	148.10	144.62	137.63	126.89	111.63	89.12	57.94
160	158.00	154.31	146.42	135.42	118.71	95.43	61.85
170	168.00	164.00	155.98	144.00	126.31	101.45	65.56
180	178.00	173.97	164.89	152.01	133.70	107.23	69.23
190	187.89	183.17	174.11	160.53	141.42	113.15	73.08
200	197.75	192.65	183.43	169.31	148.53	119.35	77.12

TABLE No. 2.

MEAN PRESSURE OF STEAM AT DIFFERENT RATES OF EXPANSION.

Initial Pressure in Pounds per Square Inch.	*Average pressure in pounds per square inch for the whole stroke.*								
	Points in the stroke at which the steam is cut off.								
	$\frac{9}{10}$	$\frac{8}{10}$	$\frac{7}{10}$	$\frac{6}{10}$	$\frac{5}{10}$	$\frac{4}{10}$	$\frac{3}{10}$	$\frac{2}{10}$	$\frac{1}{10}$
3	2.98	2.93	2.83	2.71	2.54	2.29	1.98	1.57	0.99
4	3.97	3.91	3.78	3.61	3.38	3.06	2.64	2.09	1.32
5	4.97	4.89	4.72	4.52	4.23	3.83	3.30	2.61	1.65
6	5.96	5.87	5.67	5.42	5.08	4.59	3.96	3.13	1.98
7	6.95	6.85	6.61	6.32	5.92	5.36	4.62	3.65	2.31
8	7.95	7.83	7.56	7.23	6.77	6.13	5.28	4.17	2.64
9	8.94	8.80	8.50	8.13	7.62	6.89	5.94	4.69	2.97
10	9.94	9.78	9.45	9.04	8.46	7.66	6.61	5.22	3.30
11	10.93	10.76	10.39	9.94	9.31	8.43	7.27	5.74	3.63
12	11.92	11.74	11.34	10.84	10.16	9.19	7.93	6.26	3.96
13	12.86	12.72	12.28	11.75	11.00	9.96	8.59	6.78	4.29
14	13.91	13.67	13.23	12.65	11.85	10.73	9.25	7.30	4.62
15	14.90	14.68	14.17	13.55	12.69	11.49	9.91	7.83	4.95
16	15.89	15.65	15.12	14.45	13.54	12.26	10.57	8.35	5.28
17	16.89	16.63	16.06	15.36	14.35	13.03	11.23	8.87	5.61
18	17.88	17.61	17.01	16.26	15.24	13.79	11.89	9.39	5.94
19	18.88	18.59	17.95	17.17	16.08	14.56	12.55	9.91	6.27
20	19.87	19.57	18.90	18.07	16.93	15.33	13.21	10.44	6.60

Initial Pressure in Pounds per Square Inch.	*Average pressure in pounds per square inch for the whole stroke.*								
	Points in the stroke at which the steam is cut off.								
	$\frac{9}{10}$	$\frac{8}{10}$	$\frac{7}{10}$	$\frac{6}{10}$	$\frac{5}{10}$	$\frac{4}{10}$	$\frac{3}{10}$	$\frac{2}{10}$	$\frac{1}{10}$
25	24.84	24.46	23.62	22.59	21.16	19.10	16.51	13.04	8.25
30	29.81	29.35	28.35	27.11	25.39	22.99	19.82	15.65	9.91
35	34.78	34.24	33.07	31.63	29.63	26.82	23.12	18.26	11.56
40	39.74	39.14	37.80	36.14	33.86	30.66	26.22	20.87	13.21
45	44.91	44.02	42.52	40.66	38.09	34.89	29.73	23.48	14.86
50	49.68	48.92	47.25	45.18	42.32	38.32	33.03	26.09	16.51
55	54.38	53.73	52.01	49.91	46.47	42.08	36.67	28.57	18.12
60	59.45	58.56	56.63	54.41	50.73	45.98	39.23	31.02	19.79
65	64.35	63.43	61.35	58.96	54.98	49.89	42.98	33.84	21.49
70	69.33	68.25	66.01	63.25	59.07	53.52	46.22	36.43	23.18
75	74.29	73.18	70.08	68.00	63.38	57.36	49.53	39.00	24.72
80	79.18	78.00	75.41	72.45	67.47	61.13	52.88	41.66	26.41
85	84.13	82.98	80.07	77.00	71.84	65.00	56.14	44.08	28.02
90	89.11	87.86	85.00	81.47	76.00	68.83	59.43	46.89	29.69
95	94.08	92.79	89.64	86.00	80.16	72.68	62.81	49.37	31.34
100	99.08	97.65	94.25	90.57	84.37	76.47	66.01	52 00	33.03
110	109.07	107.54	104.00	99.95	93.00	84.12	72.97	57.46	36.41
120	118.89	117.35	103.45	108.63	101.44	91.98	79.44	62.50	39.77
130	128.85	126.89	122.65	117.89	110.00	99.47	86.00	67.85	43.01
140	138.79	136.53	132.03	126.77	118.36	107.21	92.51	73.00	46.32
150	148.71	146.28	141.98	136.00	126.89	114.56	99.04	78.11	49.73
160	158.55	156 13	150.87	145.02	135.42	122.37	105.89	83.33	52.95
170	168.45	166.00	160.76	154.00	144.00	130.10	112.35	88.49	56.22
180	178.23	175.81	170.01	163.03	152.01	137.85	119.05	93.85	59.57
190	188.15	185.72	179.61	172.00	160.53	145.54	125.95	98.95	62.95
200	198.06	195.10	188.73	181.52	169.31	152.82	132.02	104.02	66.02

CUTTING OFF STEAM.

There are a great variety of expansion-valves and arrangements for cutting off steam, but the writer proposes to let the owners of these different machines explain their points of excellence for themselves, and still adheres to the rule laid down on page 11—of avoiding personalities, as well in speaking of engines that are good as in describing those which are bad. The writer wishes it to be distinctly understood that he has no interest in the success or failure of any particular engine, but will recommend to users of steam-power such engines as will show the best diagrams, according to the principles previously laid down, and that combine these good qualities, with an ability to wear well, and that do not, under ordinary circumstances, require too much attention; in other words, the requisites of a first-class engine are, strength, simplicity, and such a combination of principles as will give a first-class result, in point of economy of fuel, which last can only be shown by the application of the Indicator. A tendency not to wear well will show itself to any observer, particularly after the machine is running, if it breaks some of its lesser parts the first week. The economy of fuel on some engines may be sufficient to pay a large sum for repairing; for instance, if a new engine save $15,000

worth of coal in one year, and costs $1,000 to keep the valve gear in good repair, the credit to the new engine would still be $14,000 over the old one. All these points need to be thoroughly considered before condemning a new engine that has perhaps failed in some minor points sooner than was expected.

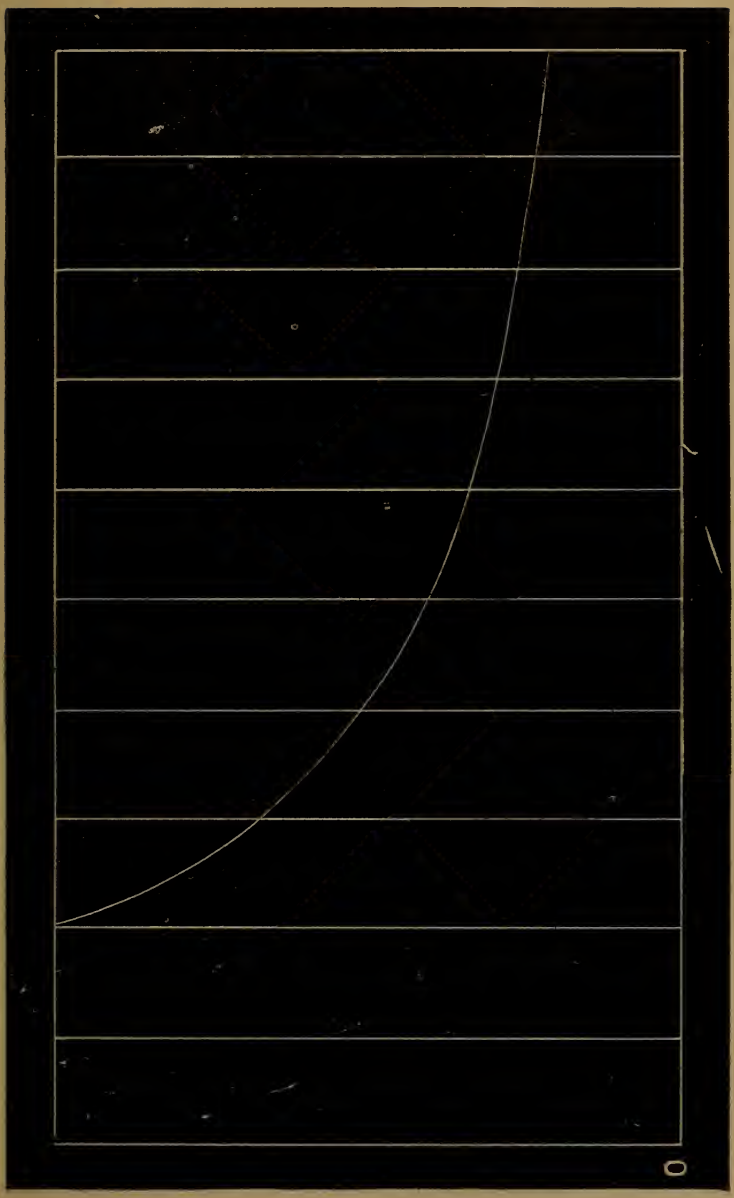
THE SLIDE-VALVE.

As is well known, the slide-valve is the simplest form of valve gear that has been devised; but an engine with this on needs very peculiar conditions to work with the best economy. For this purpose it needs a uniform load, a uniform pressure of steam, and perfect adaptation to its load, in point of size, so that it can be run without throttling. For example of a slide-valve working badly, in point of economy, take diagram No. 2, where the engine was much too large for its load. The average pressure on this diagram being less than 16 pounds, while at the same time there was 62 pounds pressure in the boiler. Thus you see the steam was got up to 62 pounds and down again to 16, when it was used, which process appears to be very much like walking up a hill and then walking down again without any definite purpose. Of course all the heat that was expended in raising that steam above 16 pounds was

lost when it came down again, as has been explained on page 84. But the conditions above named are scarce ever met with in stationary engines, although they may sometimes be found nearly on propellers or locomotives, where the engine can work right up to its full capacity. In such cases their relative economy is better, or their consumption of fuel per horse-power per hour is less than when the engine is only one-quarter, one-third, or one-half loaded, and the steam has to be raised to a high pressure in order to get a sufficient quantity of it, and then wire-drawn down again in order to use it. As a cut-off apparatus the slide-valve on stationary engines that are throttled is very inefficient; for example see again diagram No. 2, where the slide-valve was closed by lap at $\frac{75}{100}$ of the stroke, the point of closure cannot be made out on the diagram, and it is nearly or quite immaterial with reference to the final result whether the valve closed at this point or not. But, as in the cases that have been named of full loaded engines, the slide-valve may be made use of to cut off to advantage as short as $\frac{2}{3}$ the stroke, some say $\frac{1}{2}$ stroke, but this necessitates a balance-valve as the travel has to be considerable. There are many other devices for cutting off steam, many of them good, but all subject to criticism, but this is not the place to enter

upon a discussion of their merits. If the general reader has followed me through this volume I trust he has added somewhat to his store of information upon the subject of steam; and if my reader is a party owning and using steam-power, who is desirous to economize in his fuel bills, this volume tells what has been done by the author in a few instances, in his own practice, many more of which can be furnished on application. That there is a chance for economy on a large majority of the engines of the present day, there is no room to doubt; and to the student of mechanical engineering, and to professors in technical schools and colleges, or others into whose hands this volume may fall, I would state that it has been the writer's pleasure on one occasion to take Indicator diagrams for the benefit of the graduating class of a technical institute, and I take this opportunity of saying, that I will respond to institutions or individuals with pleasure, for a similar service in imparting practical knowledge of "*the use of the Steam-Engine Indicator.*"

DIAGRAM No. 1.



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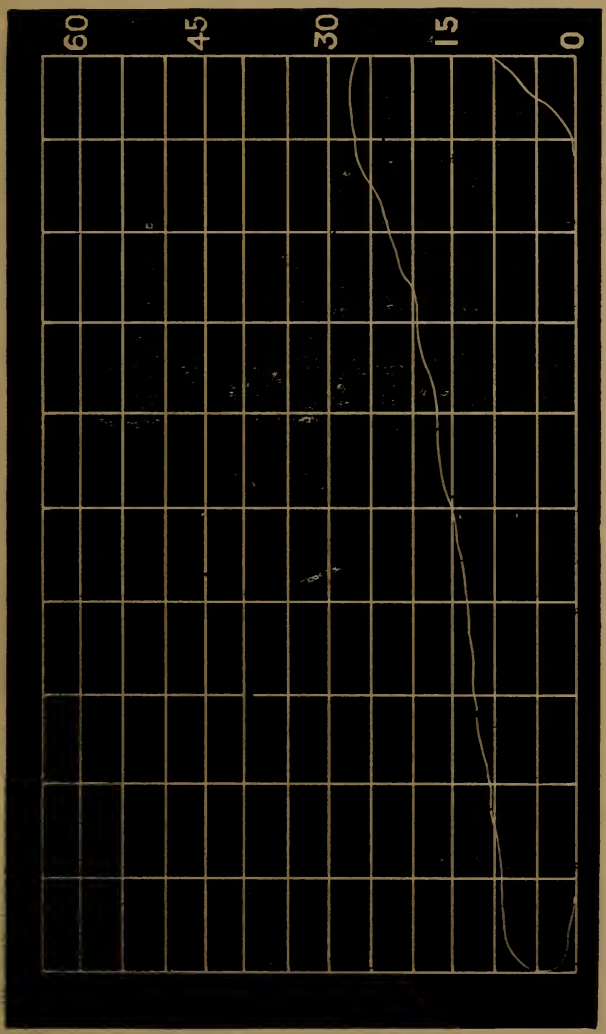

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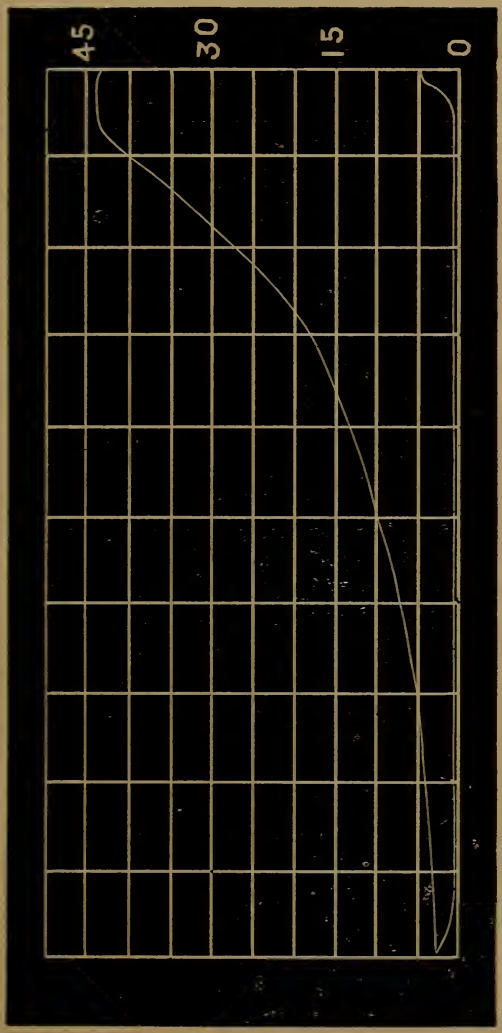

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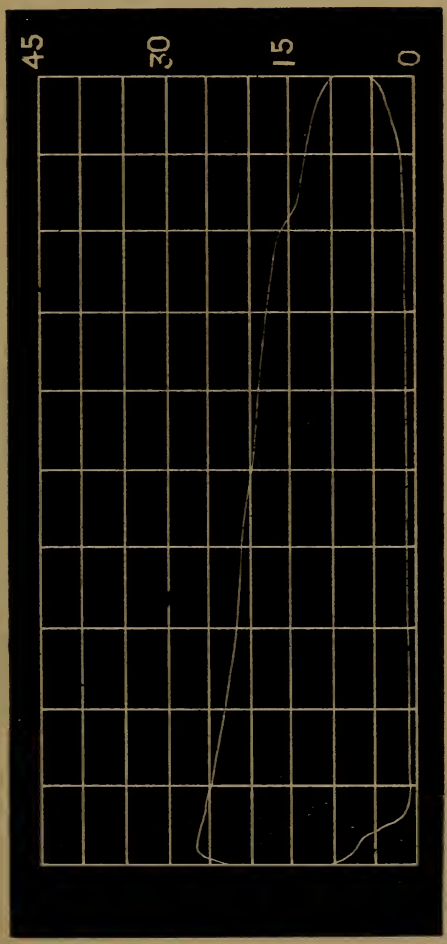

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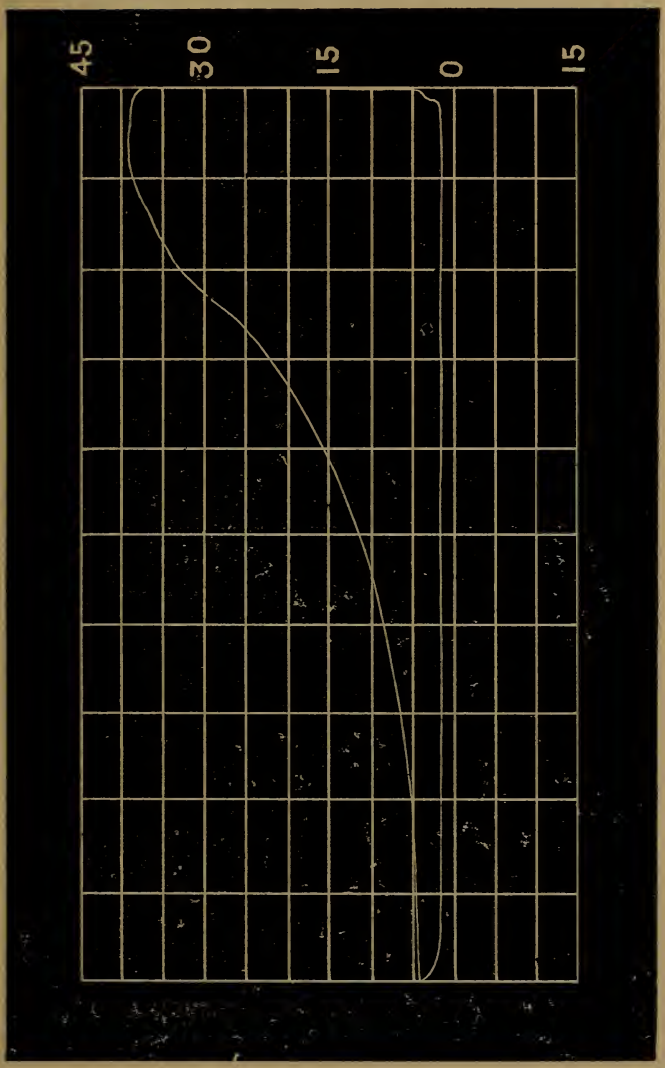

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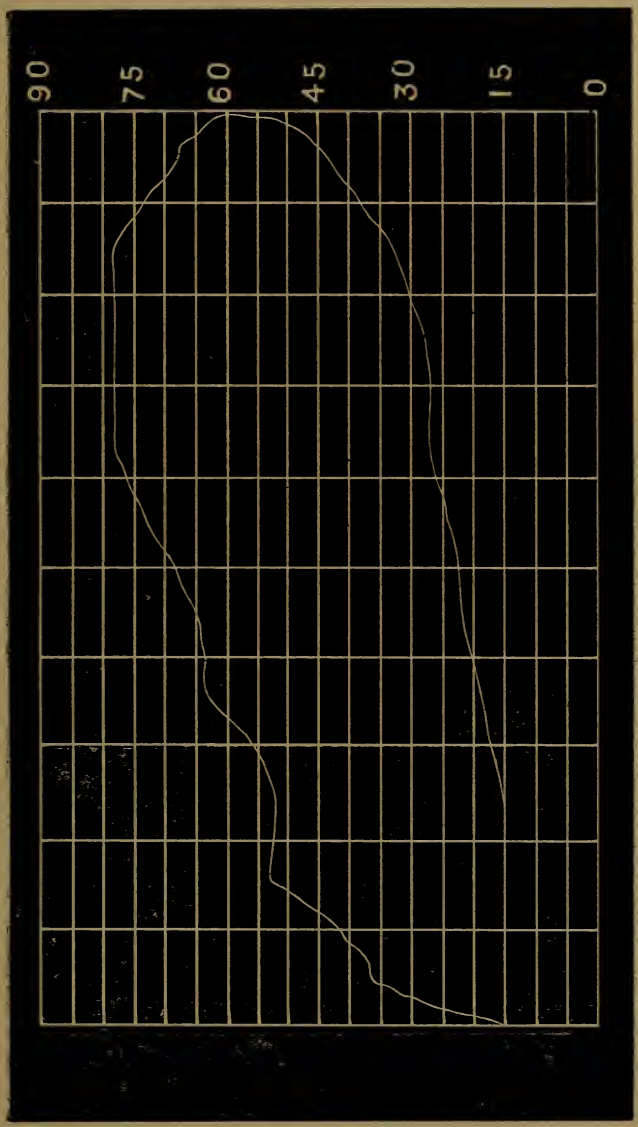

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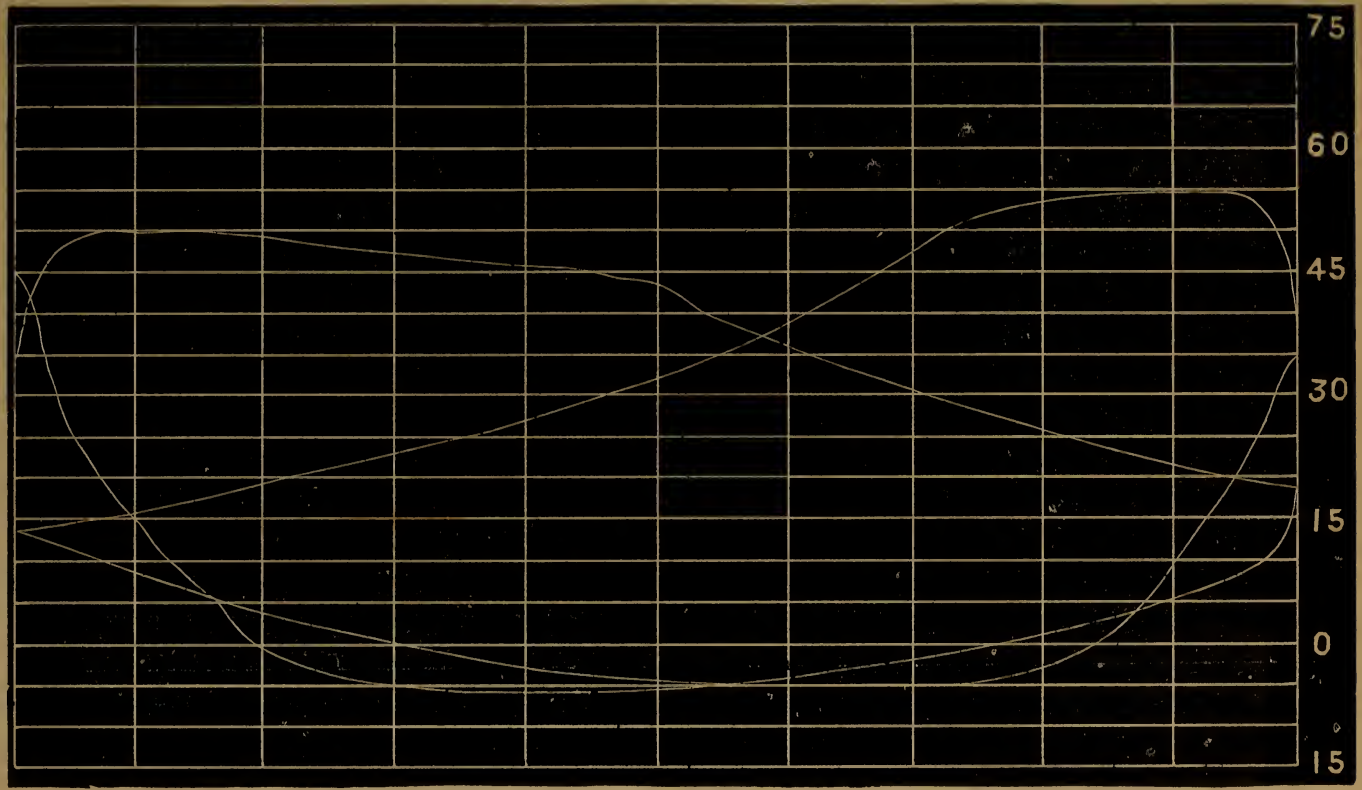

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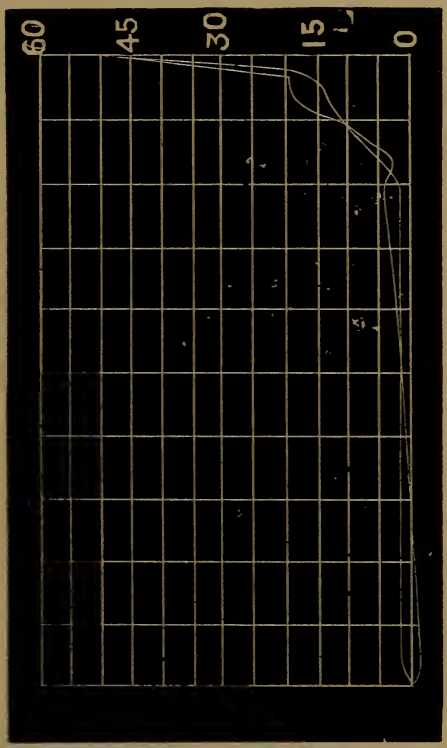

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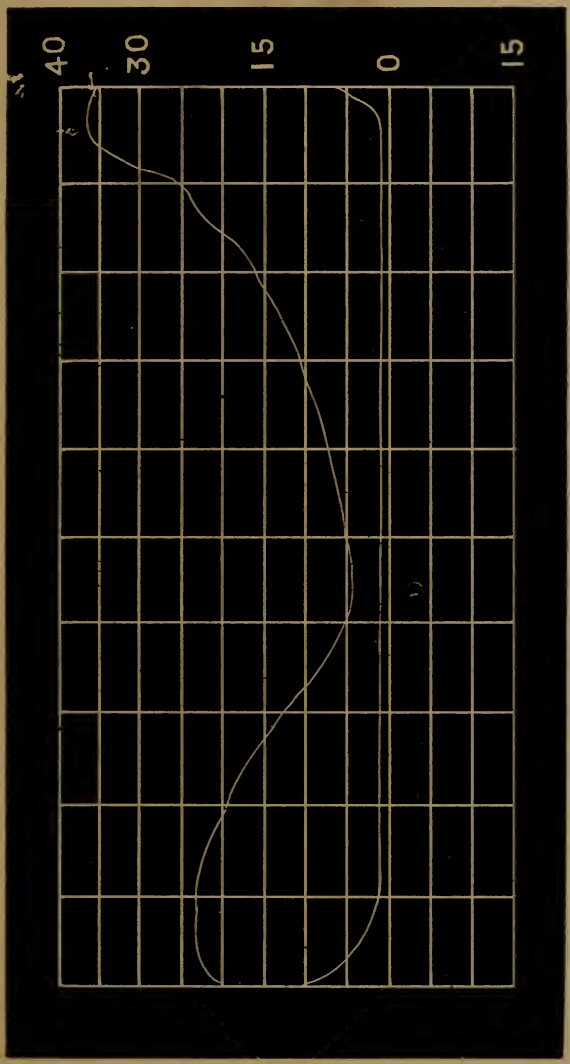

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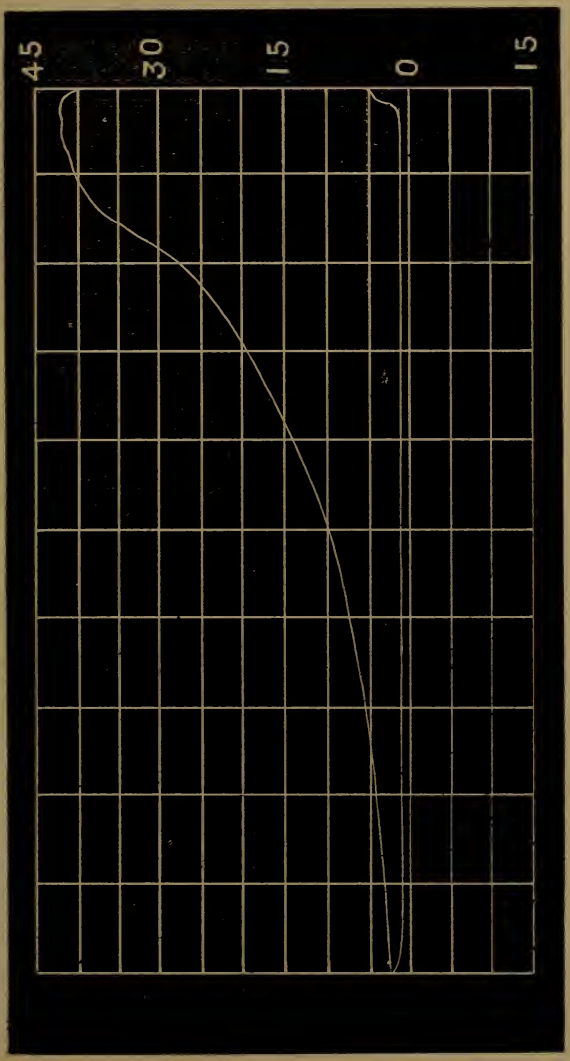

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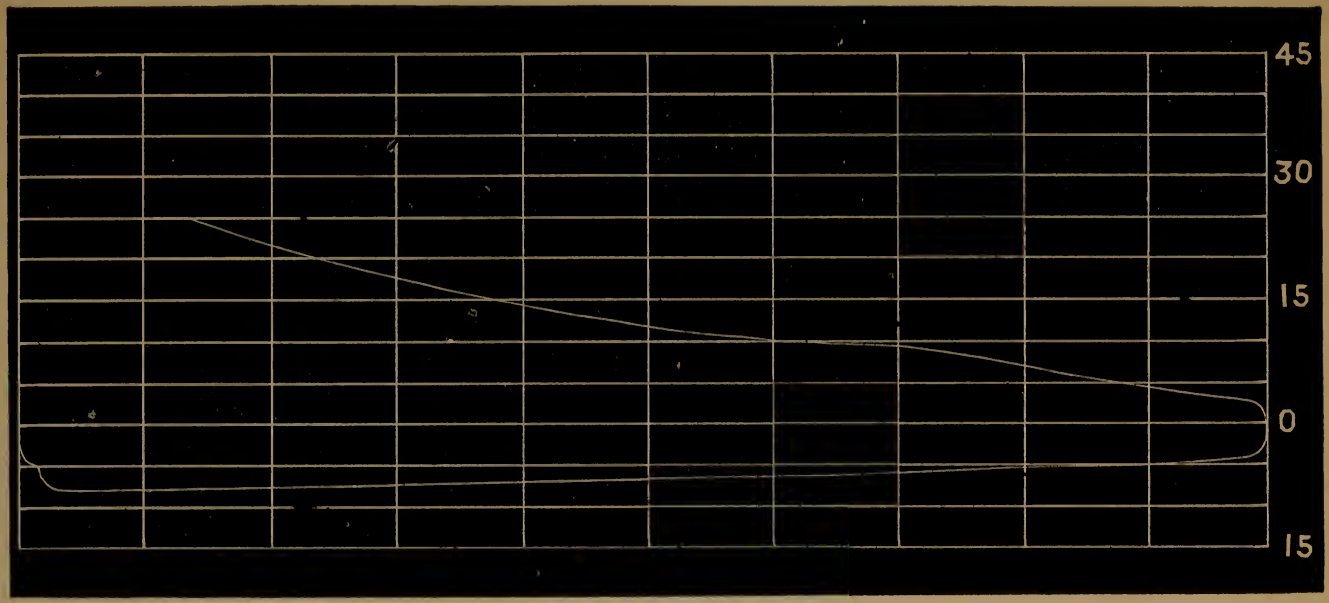

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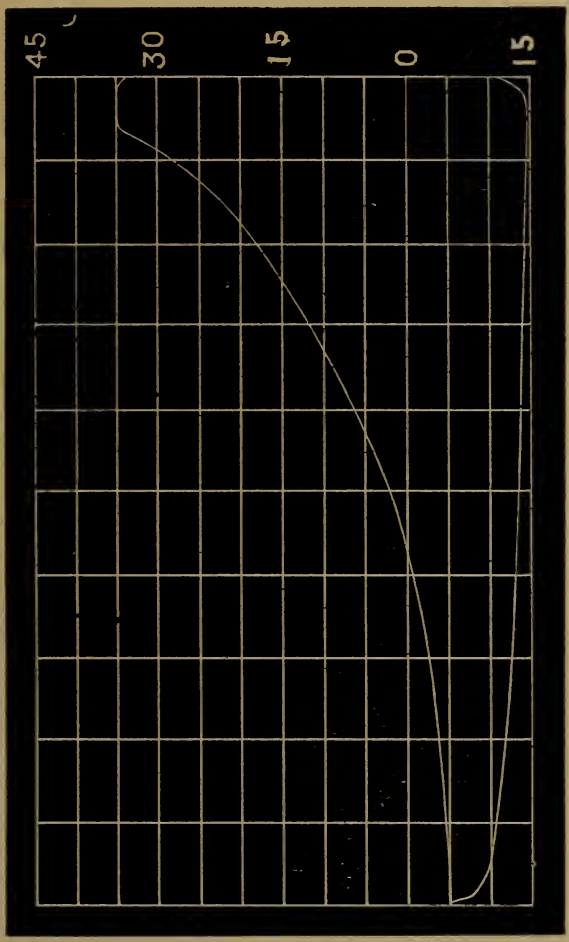

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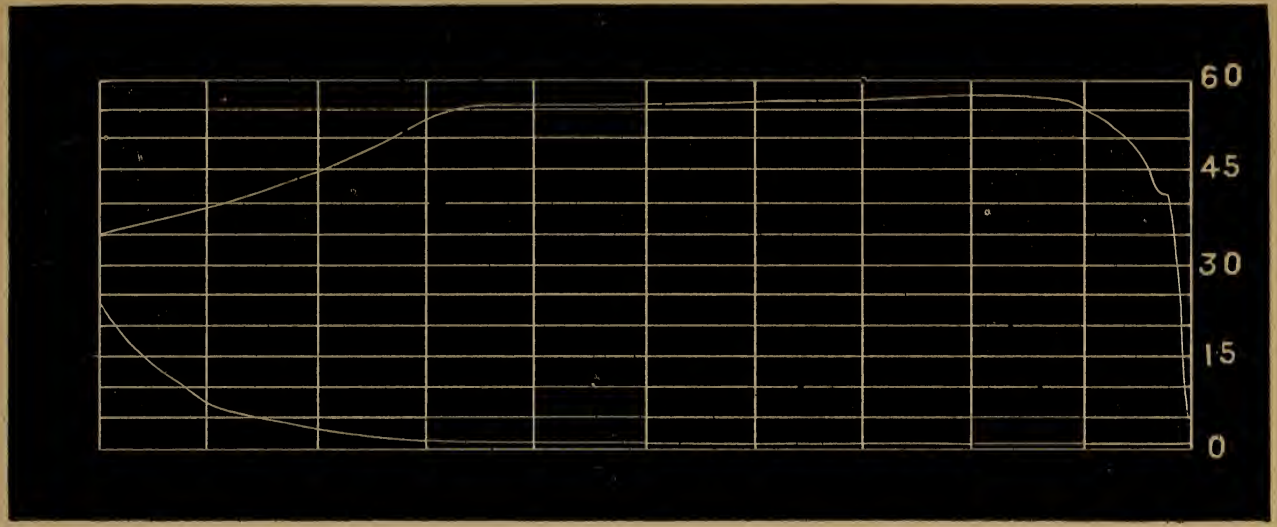

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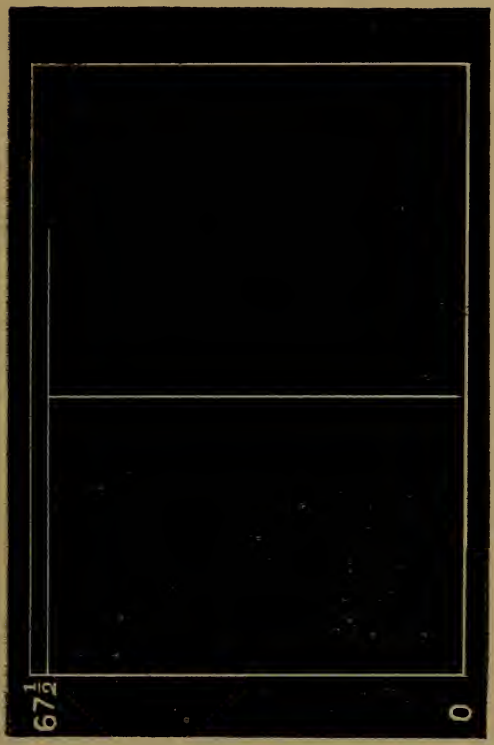

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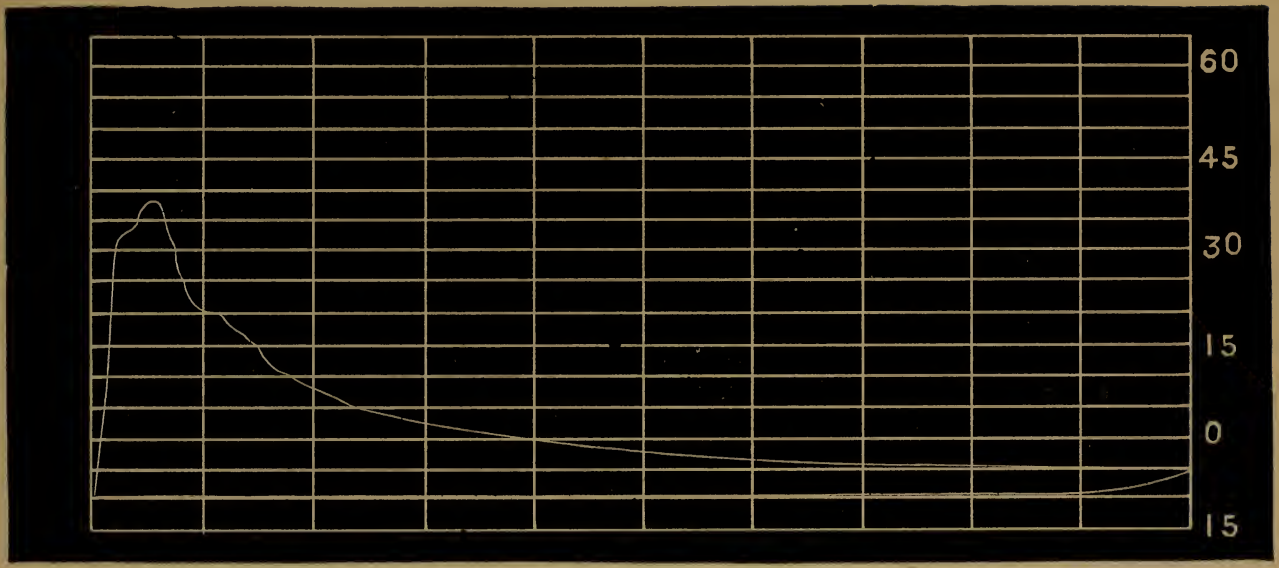

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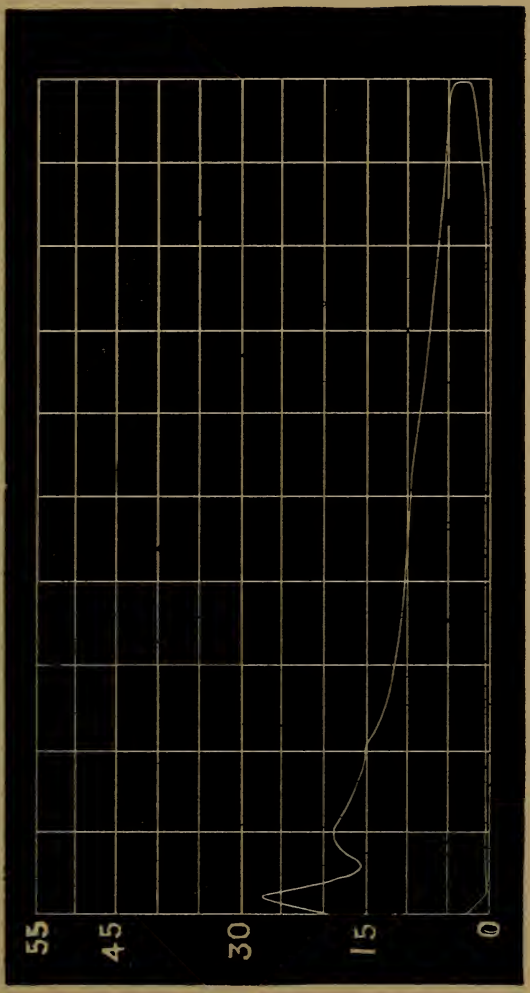

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Fig. 1

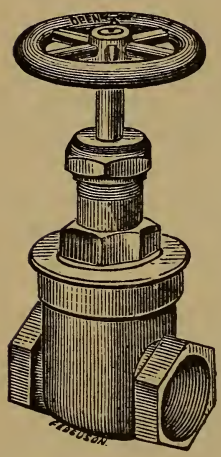
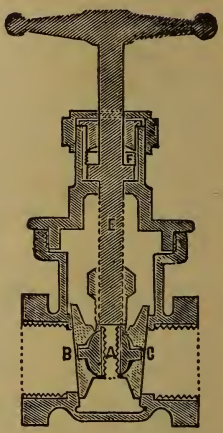


Fig. 1 represents the Ball Valve from ½ in. to 2½ in. inclusive.

Fig. 2 is a representation of a Sectional view of the Ball valve. B and C are the Disks or Gates, A is the Ball or Nut, E is the Stem, F is the Gland Ring. The Disks are shown closed against the Seats.

Fig. 2



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